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Performance Indicators for Measuring Pavement Maintenance Management

by
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Roadways are a vital element in the infrastructure of Army installations; maintenance and repair costs for roadway pavement can be significant. Recently, the Army has developed the PAVER Pavement Maintenance Management System, which combines a standardized pavement inspection procedure with information in a computer database to determine the Pavement Condition Index (PCI)—a numerical measure of the state of road pavement.

However, data on monetary expenditures are not part of the PAVER system, but are reported annually in the Army *Red Book*. In this report, PAVER indices and *Red Book* data are examined for Army Major Commands and Installations. Furthermore, this report develops an analytical method that uses both PAVER PCI and *Red Book* data to measure and rank the performance of Army installation Directorates of Engineering and Housing (DEHs) in managing pavement maintenance.

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13. ABSTRACT (Maximum 200 words)

Roadways are a vital element in the infrastructure of Army installations; maintenance and repair costs for roadway pavement can be significant. Recently, the Army has developed the PAVER Pavement Maintenance Management System, which combines a standardized pavement inspection procedure with information in a computer database to determine the Pavement Condition Index (PCI)—a numerical measure of the state of road pavement.

However, data on monetary expenditures are not part of the PAVER system, but are reported annually in the Army *Red Book*. In this report, PAVER indices and *Red Book* data are examined for Army Major Commands and Installations. Furthermore, this report develops an analytical method that uses both PAVER PCI and *Red Book* data to measure and rank the performance of Army installation Directorates of Engineering and Housing (DEHs) in managing pavement maintenance.

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FOREWORD

This work was conducted for the U.S. Army Engineering and Housing Support Center (USAEHSC), under the reimbursable task "Development of Performance Measurements for Pavements," Funding Acquisition Document (FAD) 89-80004. The USAEHSC Technical Monitor was Mr. Bob Williams, CEHSC-FB-P.

The project was performed by the U.S. Army Construction Engineering Research Laboratory (USACERL) through a contract to Research Associates, Champaign, IL. Mr. Benjamin Sliwinski is employed at Research Associates. Mr. Robert Neathammer, Facility Systems Division (FS), was Principal Investigator. Dr. Michael J. O'Connor is Chief of USACERL-FS. The USACERL technical editor was Mr. William J. Wolfe, Information Management Office.

COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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PAVEMENT MAINTENANCE MANAGEMENT

1 INTRODUCTION

Background

Roadways are a vital element in the infrastructure of an Army installation, and maintenance and repair costs for roadway pavement can be significant. Recently, the Army has developed and implemented the PAVER Pavement Maintenance Management System[1] in order to more effectively manage pavement maintenance. This system consists of a standardized pavement inspection procedure and a computer database, which allows determination of a Pavement Condition Index (PCI). The PCI, which is a numerical index from zero to 100, is a measure of the pavement's structural integrity and operational condition. The PCI is computed as a function of distress type, severity, and quantity, and provides an objective and consistent measure of pavement condition. The PAVER system has been adopted by 55 Army installations, each of which has at least 1 year's measured PCI.

Data on monetary expenditures for pavement maintenance and repair are not a part of the PAVER system. This data is currently reported on an annual basis in the Army "Red Book."

It is believed that combining the Red Book expenditure data with the PAVER system PCI data provides an opportunity for assessing an Army installation's effectiveness in managing the maintenance and repair of its pavement.

Objective

The objective of the work presented in this report was to develop an analytical method of using available Red Book and PAVER PCI data to measure the performance of an Army installation Directorate of Engineering and Housing (DEH) in managing pavement maintenance.

Approach

Red Book data were obtained in ENABLE database format from the U.S. Army Engineering and Housing Support Center (EHSC) at Ft. Belvoir, VA. Supplemental hardcopy Red Book data was obtained from the U.S. Army Construction Engineering Research Laboratory (USACERL). PCI data was obtained from USACERL from the PAVER database for all U.S. Army Forces Command (FORSCOM), U.S. Army Training and Doctrine Command (TRADOC), and U.S. Army Materiel Command (AMC) installations which have implemented the PAVER System.

Red Book data was analyzed to examine yearly trends in pavement maintenance expenditures, and to determine potential indicators of performance in pavement maintenance management. In addition, the data was reviewed to identify missing or erroneous data.

PAVER system PCI data as received form USACERL was processed to determine installation average values for PCI, area of pavement, pavement age, inspection year, and rate of deterioration. During this processing, error checking was performed and erroneous or missing data identified. The final averaged data was combined with similarly averaged Red Book data for final analysis.

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[1]Mohamed Y. Shahin, *Pavement Maintenance Management: The Micro PAVER System*, Technical Report (TR) M-87/12/ADA187360 (U.S. Army Construction Engineering Research Laboratory [USACERL], September 1987).

In the final analysis, the combined PAVER and Red Book data were first subjected to correlation analysis. Scatterplots were produced for pairs of data showing some degree of correlation; these scatterplots were then reviewed to determine potential pavement maintenance performance indicators. A number of potentially useful parameters were identified which were then combined into pavement management indices (PMIs). Hypothetical rankings were then developed based on these indices.

2 ANALYSIS OF RED BOOK DATA

As indicated, Red Book data was provided in ENABLE database format for annual pavement maintenance and repair expenditures. Of the data elements provided, the element for the K5110 activity, "Roadways," was selected for analysis. Data were selected for the FORSCOM, TRADOC, and AMC installations listed in Table 1 below. For each installation,data were provided for: the budget unit quantity of pavement (BUQ) in thousands of square yards (KSY); the annual maintenance and repair cost (TOTCST) in dollars; and, the unit cost (UCOST) in dollars per thousand square yards. Also reported were the number of equivalent lane-miles and the unit cost per lane-mile. The lane-mile data was found to be erroneous, the conversion factor from square yards to lane-miles being consistently misapplied. Surprisingly, however, the unit cost per lane mile data was accurate. In addition to the error in the lane-mile data, one erroneous data point for Ft. McCoy (TOTCST) was deleted and corrected using the hardcopy Red Book data.

Table 1. Installations With Red Book Data

Installation	MACOM	PAVER Data File
FT. BRAGG	FORSCOM	BRAG
FT. CAMPBELL	FORSCOM	CAMP
FT. CARSON	FORSCOM	CARS
FT. DEVENS	FORSCOM	DEVN
FT. DRUM	FORSCOM	DRUM
FT. HOOD	FORSCOM	HOOD
FT. INDIANTOWN GAP	FORSCOM	INDI
FT. SAM HOUSTON	FORSCOM	SAMH
FT. LAWTON	FORSCOM	
FT. LEWIS	FORSCOM	LEWS
FT. MCCOY	FORSCOM	MCCY
FT. MCPHERSON	FORSCOM	MCPH
FT. MEADE	FORSCOM	
FT. RILEY	FORSCOM	RILY
FT. SHERIDAN	FORSCOM	SHER
FT. STEWART	FORSCOM	STEW
FT. IRWIN	FORSCOM	IRWN
PRESIDIO OF SAN FRANCISCO	FORSCOM	PRES
VANCOUVER BARRACKS	FORSCOM	
YAKIMA FIRING CENTER	FORSCOM	
FT. GREELY	FORSCOM	GREE
FT. RICHARDSON	FORSCOM	RICH
FT. WAINWRIGHT	FORSCOM	WAIN
PETROLEUM DIVISION	FORSCOM	
PANAMA	FORSCOM	
FT. ORD	FORSCOM	ORD
FT. POLK	FORSCOM	POLK
FT. BELVOIR	TRADOC	
FT. BENNING	TRADOC	BENN
FT. BLISS	TRADOC	
FT. CHAFFEE	TRADOC	CHAF
FT. DIX	TRADOC	DIX
FT. EUSTIS	TRADOC	EUST
FT. GORDON	TRADOC	
FT. BENJAMIN HARRISON	TRADOC	
FT. A.P. HILL	TRADOC	HILL
FT. JACKSON	TRADOC	JACK
FT. KNOX	TRADOC	KNOX
FT. LEAVENWORTH	TRADOC	
FT. LEE	TRADOC	
FT. MCCLELLAN	TRADOC	
FT. MONROE	TRADOC	
FT. HAMILTON	TRADOC	
FT. PICKETT	TRADOC	PICK
FT. RUCKER	TRADOC	
FT. SILL	TRADOC	
FT. LEONARD WOOD	TRADOC	LEOW
CARLISLE BARRACKS	TRADOC	

Table 1 Continued. Installations With Red Book Data

Installation	MACOM	PAVER Data File	Installation	MACOM	PAVER Data File
ANNISTON	AMC		LAKE CITY	AMC	
LETTERKENNY	AMC		LONE STAR	AMC	LSTR
LEXINGTON BG	AMC		LONGHORN	AMC	LHRN
NEW CUMBERLAND	AMC		LOUISIANA	AMC	
PICATINNY	AMC		MILAN	AMC	
PINE BLUFF	AMC		NEWPORT	AMC	
RED RIVER	AMC		RADFORD	AMC	
REDSTONE	AMC		RAVENNA	AMC	
ROCK ISLAND	AMC		RIVERBANK	AMC	
ROCKY MOUNTAIN	AMC		SCRANTON	AMC	
SACRAMENTO	AMC		SUNFLOWER	AMC	
SAVANNA	AMC		TWIN CITIES	AMC	
SENECA	AMC	SENE	ETHAN ALLEN	AMC	
SHARPE	AMC		VOLUNTEER	AMC	
SIERRA	AMC	SERA	HAWTHORNE	AMC	
TOBYHANNA	AMC		MAINZ	AMC	
TOOLE	AMC		MISSISSIPPI	AMC	
WATERVLIET	AMC		LIMA	AMC	
CORPUS CHRISTI	AMC		DETROIT ARSENAL	AMC	
MCALESTER	AMC		FT. MONMOUTH	AMC	
PUEBLO DEPOT	AMC		JEFFERSON	AMC	
FT. WINGATE	AMC		ST. LOUIS SUP	AMC	
UMATILLA	AMC		ARMY MET AND MECH	AMC	
BADGER	AMC	BADG	HARRY DIAMOND	AMC	
CORNHUSKER	AMC		NATICK	AMC	
HOLSTON	AMC		WHITE SANDS	AMC	
INDIANA	AMC		YUMA	AMC	
IOWA	AMC		DUGWAY	AMC	
JOLIET	AMC		ABERDEEN	AMC	
KANSAS	AMC				

Of the Red Book data, only the BUQ, TOTCST, and UCOST data were subjected to analysis. Data were available on floppy disk for the years 1980, 81, 83, 84, and 85, for FORSCOM and AMC; and the years 1980, 81, 84, and 85 for TRADOC. Additional hardcopy Red Book data were obtained from USACERL for the years 1986 and 1987 and keyed into the existing ENABLE database. The Red Book data were analyzed as follows.

Summary Statistics

Summary statistics were developed for: BUQ, the pavement area in KSY; TOTCST, the annual maintenance and repair cost reported as activity K5110; and UCOST, the unit cost for maintenance and repair, in dollars per KSY. Summary statistics were developed separately for FORSCOM, TRADOC, and AMC installations for the years 1980 to 1987. The summary statistics are shown in Tables 2 - 5 below.

Table 2. Summary Statistics For Red Book Data, 1980 - 1981

Forscom 80

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	2234.48	2295.48	3.00	7674.00	55862.00	25
TOTCST	323101.20	276659.03	237.00	1098889.0	8077530.00	25
UCOST	254.21	366.35	24.99	1830.24	6355.22	25

Tradoc 80

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	1865.14	1713.75	123.00	6590.00	39168.00	21
TOTCST	389577.38	290064.51	39296.00	998373.00	8181125.00	21
UCOST	336.73	291.75	47.44	1097.07	7071.34	21

AMC 80

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	1038.32	993.56	23.00	4844.00	35303.00	34
TOTCST	224689.44	307642.55	3794.00	1338360.0	7639441.00	34
UCOST	477.56	1221.76	4.07	7171.94	16236.96	34

Forscom 81

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	1900.15	1579.22	45.00	5592.00	49404.00	26
TOTCST	306717.23	293850.90	0.0	1121750.0	7974648.00	26
UCOST	187.27	159.17	0.0	542.72	4869.00	26

Tradoc 81

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	1927.48	1629.09	123.00	6579.00	40477.00	21
TOTCST	460885.62	698842.12	60919.00	3337596.0	9678598.00	21
UCOST	309.75	243.92	36.22	1013.80	6504.69	21

AMC 81

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	1172.75	1927.36	55.00	11552.00	42219.00	36
TOTCST	298050.08	352326.31	1607.00	1351676.0	10729803.00	36
UCOST	410.51	594.60	1.81	3057.38	14778.30	36

Table 3. Summary Statistics For Red Book Data, 1983 - 1984

Forscom 83

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	2294.12	2223.44	42.00	9136.00	59647.00	26
TOTCST	667348.85	623403.64	0.0	2322289.0	17351070.00	26
UCOST	393.11	327.59	0.0	1249.89	10220.81	26

AMC 83

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	1033.04	1022.65	23.00	6511.00	57850.00	56
TOTCST	309103.25	483722.24	0.0	2230926.0	17309782.00	56
UCOST	383.57	535.96	0.0	3495.41	21480.01	56

Forscom 84

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	2063.85	1690.52	42.00	5725.00	53660.00	26
TOTCST	872402.12	1034508.75	1377.00	4581741.0	22682455.00	26
UCOST	439.64	376.77	32.79	1651.76	11430.63	26

Tradoc 84

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	2120.95	1716.53	137.00	6683.00	44540.00	21
TOTCST	558719.86	583441.85	14071.00	1958174.0	11733117.00	21
UCOST	335.51	292.90	16.12	1110.08	7045.64	21

AMC 84

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	1089.48	1081.86	23.00	6521.00	61011.00	56
TOTCST	343717.00	467219.92	2981.00	2191026.0	19248152.00	56
UCOST	436.11	523.12	2.16	2469.19	24422.42	56

Table 4. Summary Statistics For Red Book Data, 1985 - 1986

Forscom 85

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	1843.20	1582.29	83.00	5325.00	55296.00	30
TOTCST	924279.30	928540.43	8077.00	3150009.0	27728379.00	30
UCOST	528.18	535.46	5.38	2023.00	15845.45	30

Tradoc 85

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	1886.68	1611.10	137.00	6683.00	41507.00	22
TOTCST	514711.23	679231.71	0.0	2490920.0	11323647.00	22
UCOST	258.32	223.10	0.0	660.68	5683.09	22

AMC 85

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	1106.71	1149.89	8.00	6524.00	64189.00	58
TOTCST	257336.74	307864.59	0.0	1480469.0	14925531.00	58
UCOST	330.42	378.24	0.0	2114.64	19164.60	58

Forscom 86

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	2750.11	1831.02	108.00	6443.00	52252.00	19
TOTCST	1148200.9	1046610.62	51908.00	3883578.0	21815817.00	19
UCOST	477.18	412.61	60.92	1464.75	9066.46	19

Tradoc 86

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	2270.00	2111.67	153.00	6724.00	40860.00	18
TOTCST	736031.33	856820.53	31280.00	3486931.0	13248564.00	18
UCOST	409.88	365.82	31.82	1494.20	7377.91	18

AMC 86

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	1948.43	3139.65	31.00	22119.00	103267.00	53
TOTCST	475496.64	756887.51	2184.00	3653538.0	25201322.00	53
UCOST	343.58	409.92	10.55	1851.00	18209.80	53

Table 5. Summary Statistics For Red Book Data, 1987

Forscom 87

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	2725.60	1866.76	102.00	6972.00	54512.00	20
TOTCST	898012.30	1227290.85	120.00	5675452.0	17960246.00	20
UCOST	433.73	528.68	.08	2113.76	8674.52	20

Tradoc 87

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	2400.29	2259.59	153.00	7723.00	40805.00	17
TOTCST	544337.24	711253.17	19614.00	2683746.0	9253733.00	17
UCOST	260.45	255.88	26.93	988.10	4427.72	17

AMC 87

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
BUQ	1595.73	1883.30	11.00	12037.00	89361.00	56
TOTCST	421978.29	646140.72	108.00	3706698.0	23630784.00	56
UCOST	506.92	836.64	.06	4945.45	28387.68	56

Because N, the number of installations, varied from year to year due to missing or bad data, the mean total cost and the mean unit cost are the more useful statistics. The data from Tables 2 - 5 for these variables are summarized in the bar charts shown in Figures 1 and 2. The dollar amounts are not adjusted for inflation.

Inspection of Figures 1 and 2 reveals a well defined trend in the FORSCOM data for this period, and a more erratic pattern for the TRADOC and AMC data. The average annual cost for pavement maintenance in FORSCOM is seen to steadily increase, peaking in 1986. The TRADOC data, although more erratic, also peaks in 1986, as does the AMC data. On a unit cost basis, the FORSCOM data peaks in 1985, while the TRADOC data still peaks in 1986, and the AMC data peaks in 1987. The TRADOC expenditures are seen to be consistently less than those for FORSCOM after 1983, on a unit cost basis, and also lower than AMC for every year but 1986. Without additional information however, it is difficult to make any judgements regarding this cost difference. It is precisely for this reason that the PAVER data, to be examined in the next chapter, is so important.

Weighted Averages

The average unit cost data presented in Figures 1 and 2 represents the average unit cost per installation for each command. In comparing the two commands directly, a more useful statistic would be the average unit cost per square yard for the command. This weighted average is calculated by taking the total annual cost for the command and dividing it by the total square yardage of pavement in the command. The weighted average unit costs are shown in Figures 3 and 4. Figure 4 presents the costs adjusted for inflation assuming an annual rate of 4.5%. The trends observed in Figures 3 and 4 are similar to those observed in Figure 2; except that on this basis, the AMC data is now also less than FORSCOM for every year after 1983.

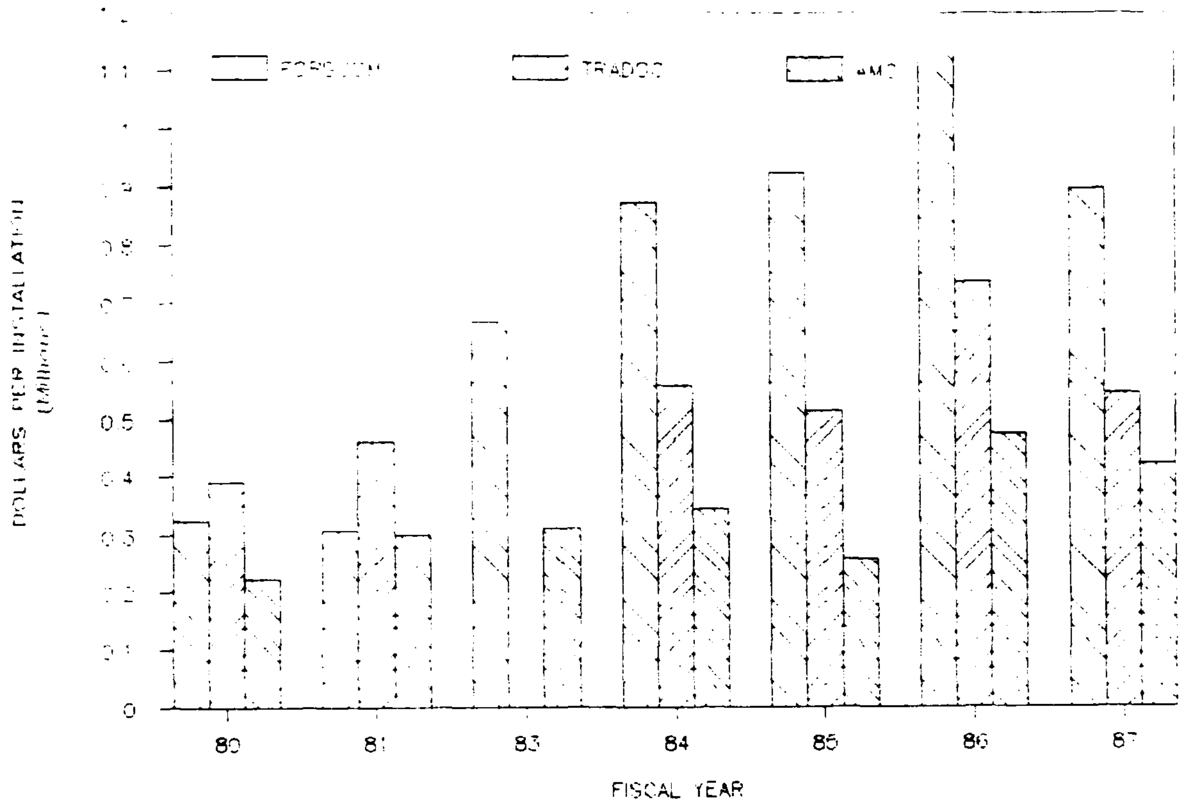

Figure 1. Average annual pavement maintenance unit cost—dollars/installation (millions.)

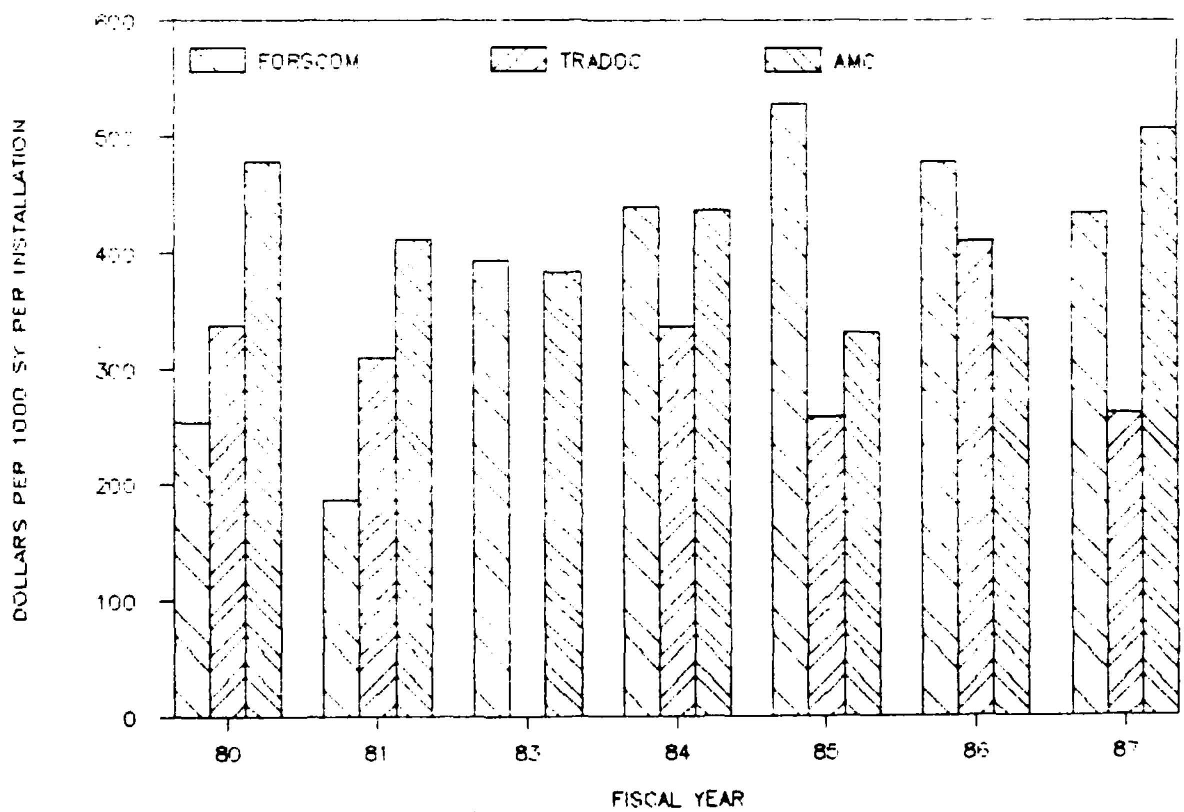

Figure 2. Average annual pavement maintenance unit cost—dollars/1000 sy/installation.

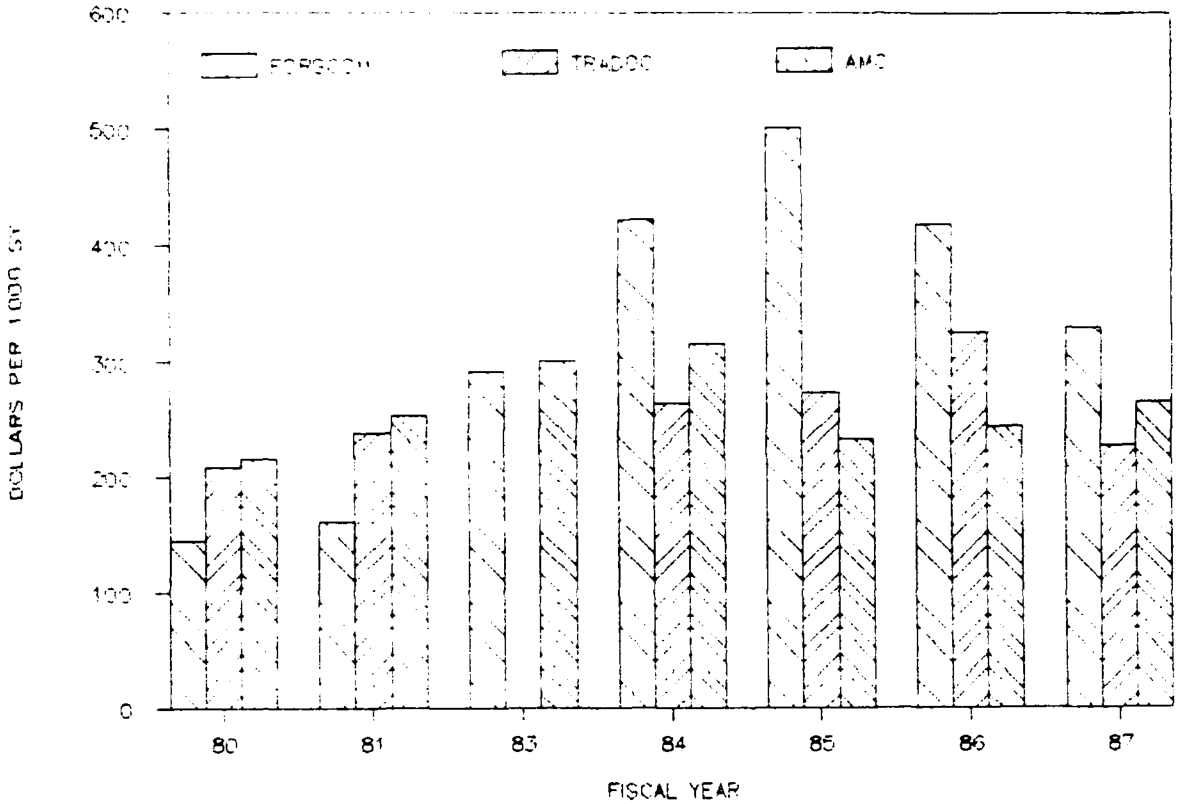

Figure 3. Annual weighted average unit cost—dollars/1000 sy/installation.

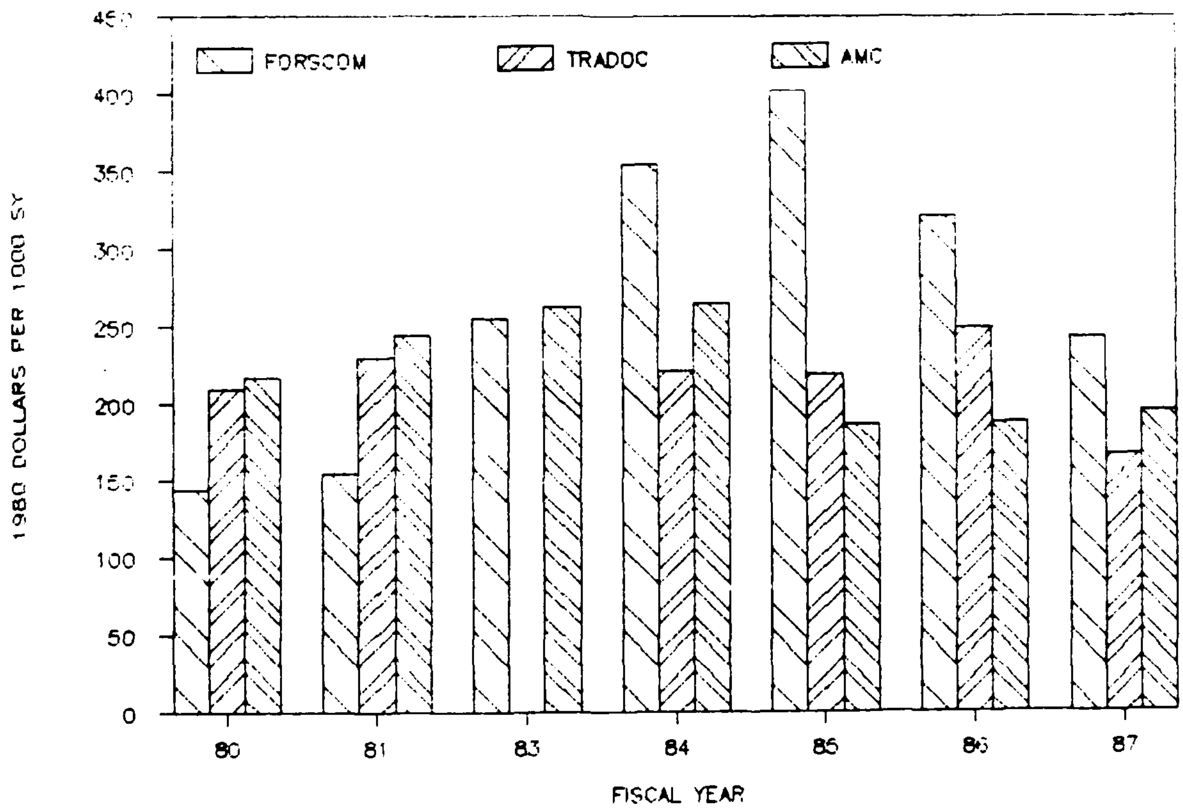

Figure 4. Annual inflation-adjusted (4.5%) average unit cost—dollars/1000 sy/installation.

Installation Trends

Trends in spending for pavement maintenance for individual installations are presented in Figures 5 through 14. Because of the small amount of data, (7 to 5 years), this data is of limited use. However, Figures 5 to 14 provide a sample of the trends observed for the individual installations.

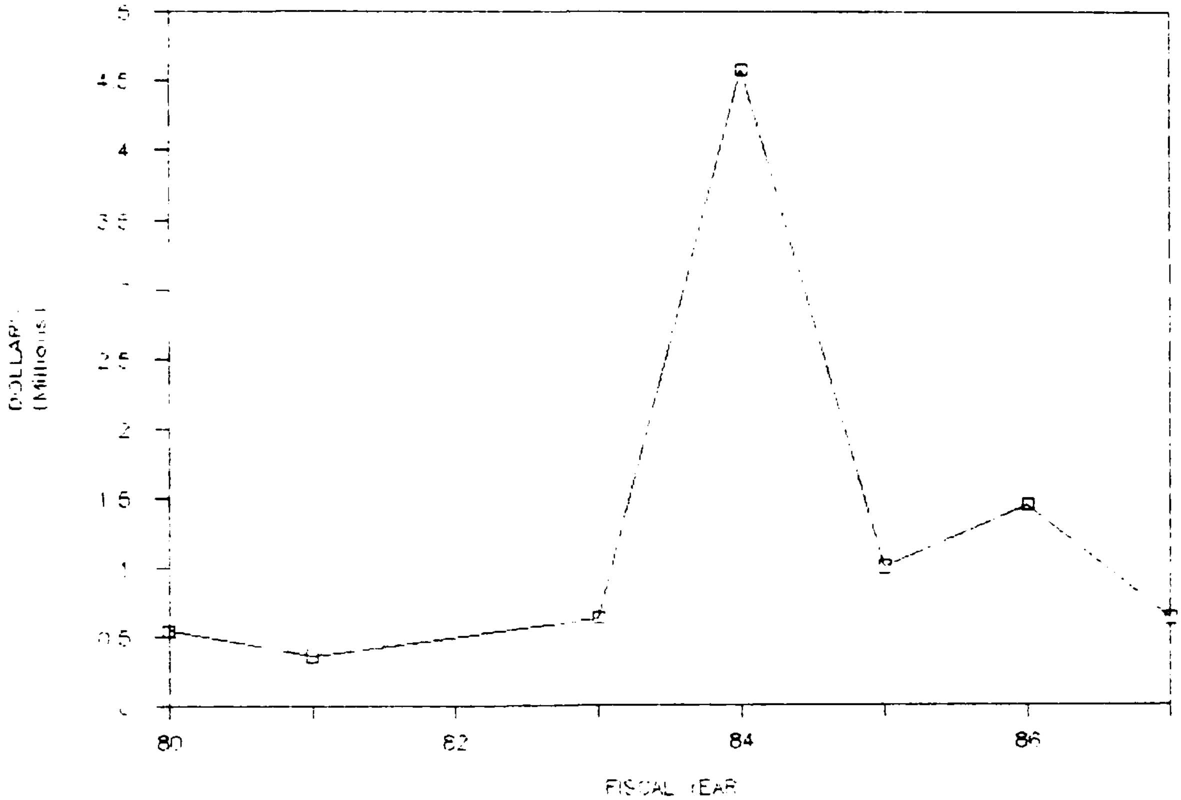

Figure 5. Annual spending for roadways—Ft. Bragg.

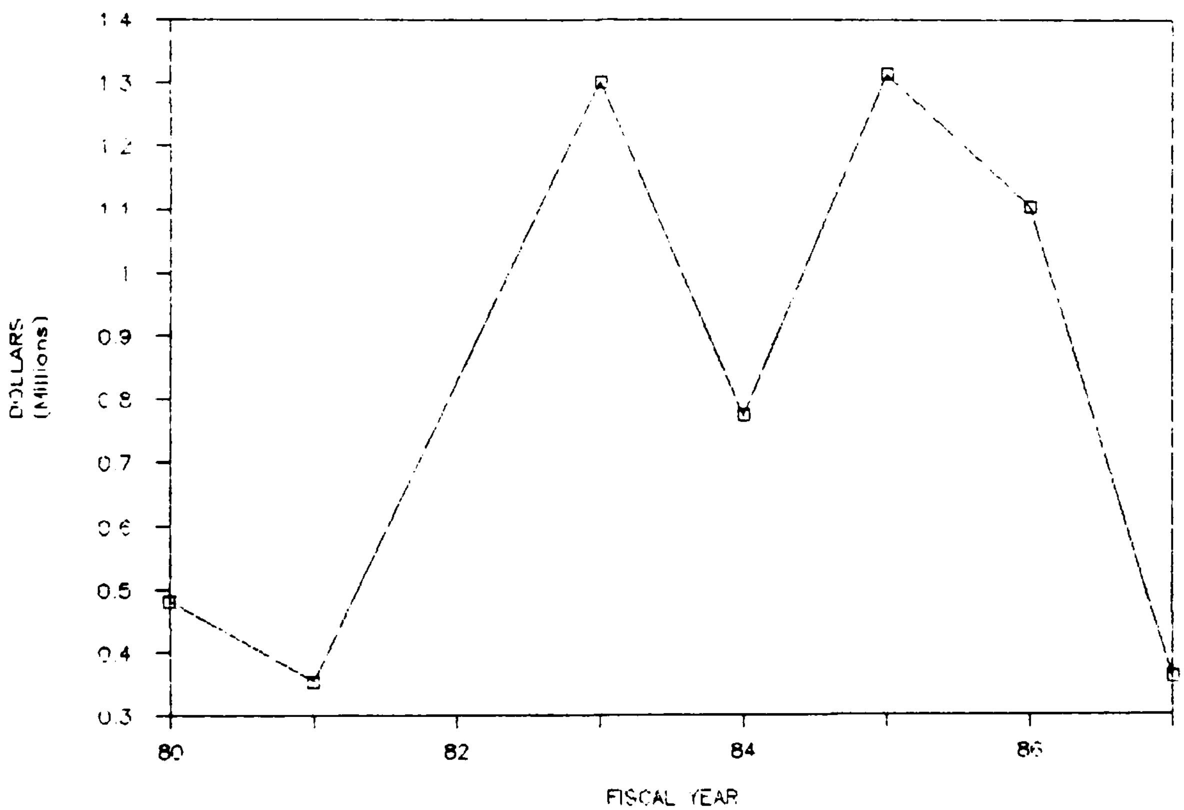

Figure 6. Annual spending for roadways—Ft. Campbell.

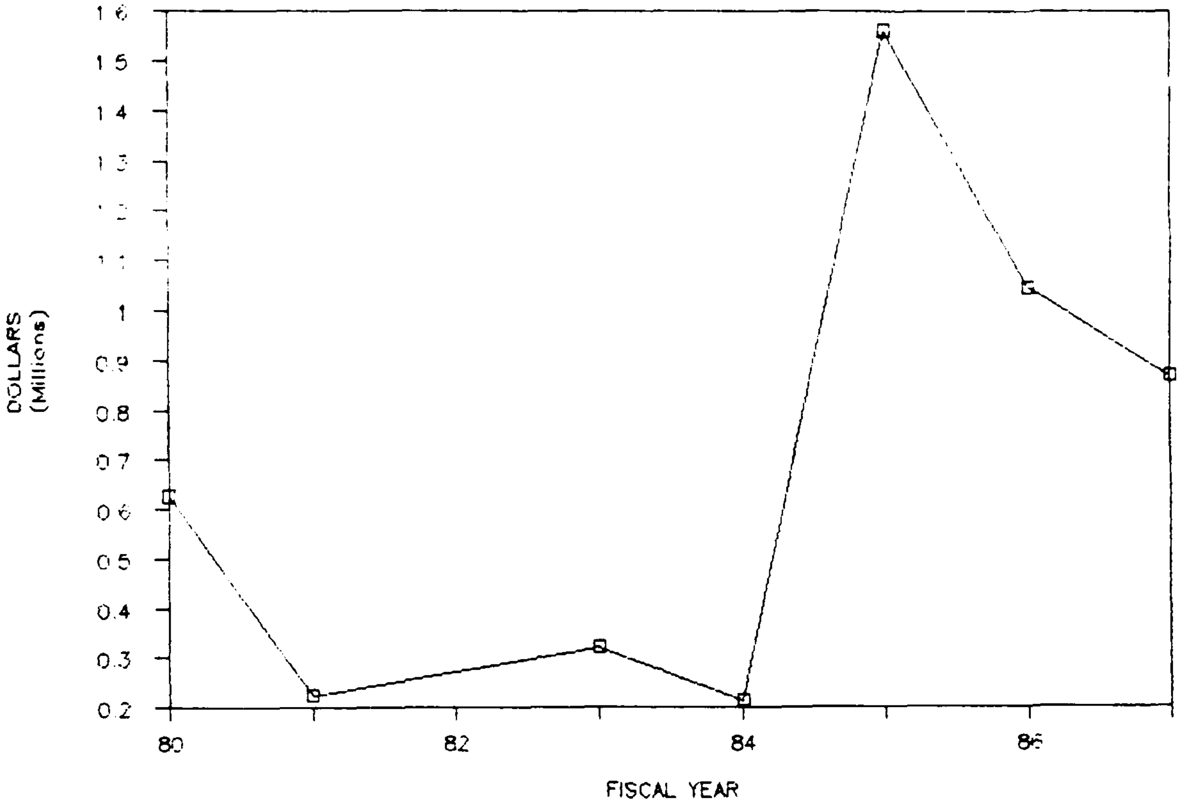

Figure 7. Annual spending for roadways—Ft. Lewis.

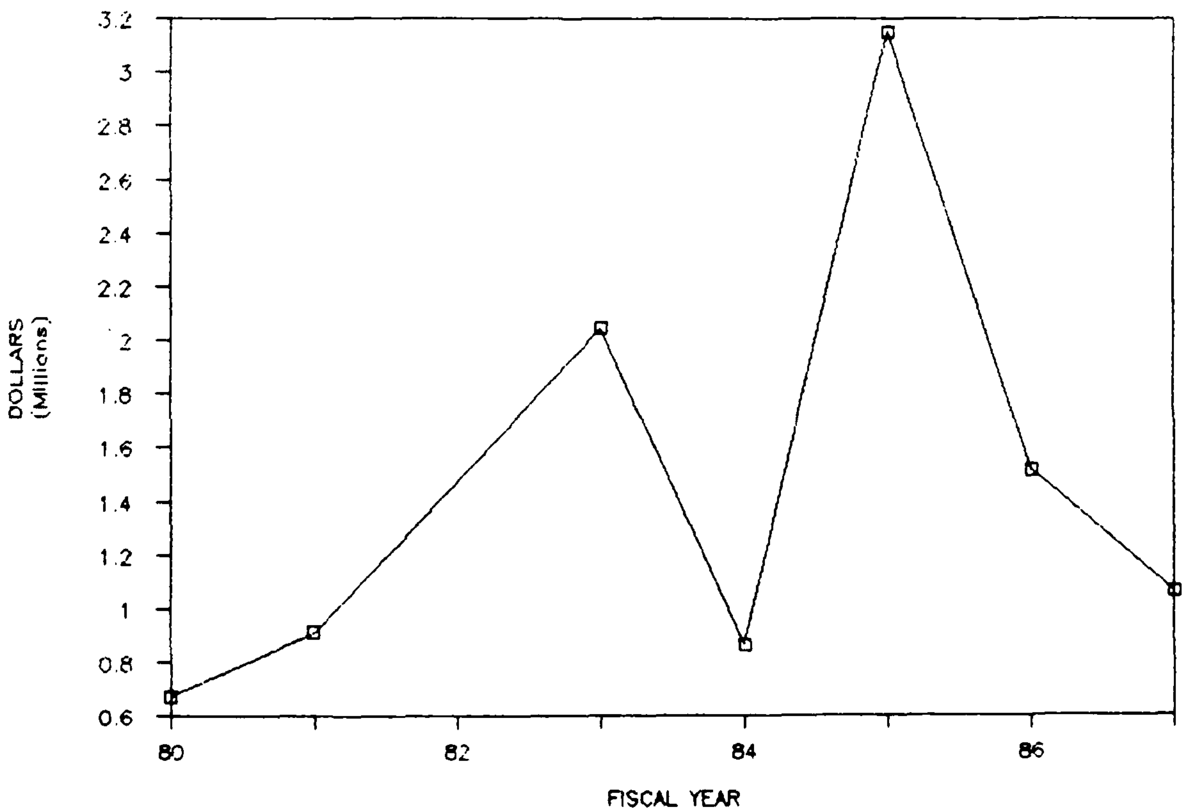

Figure 8. Annual spending for roadways—Ft. Polk.

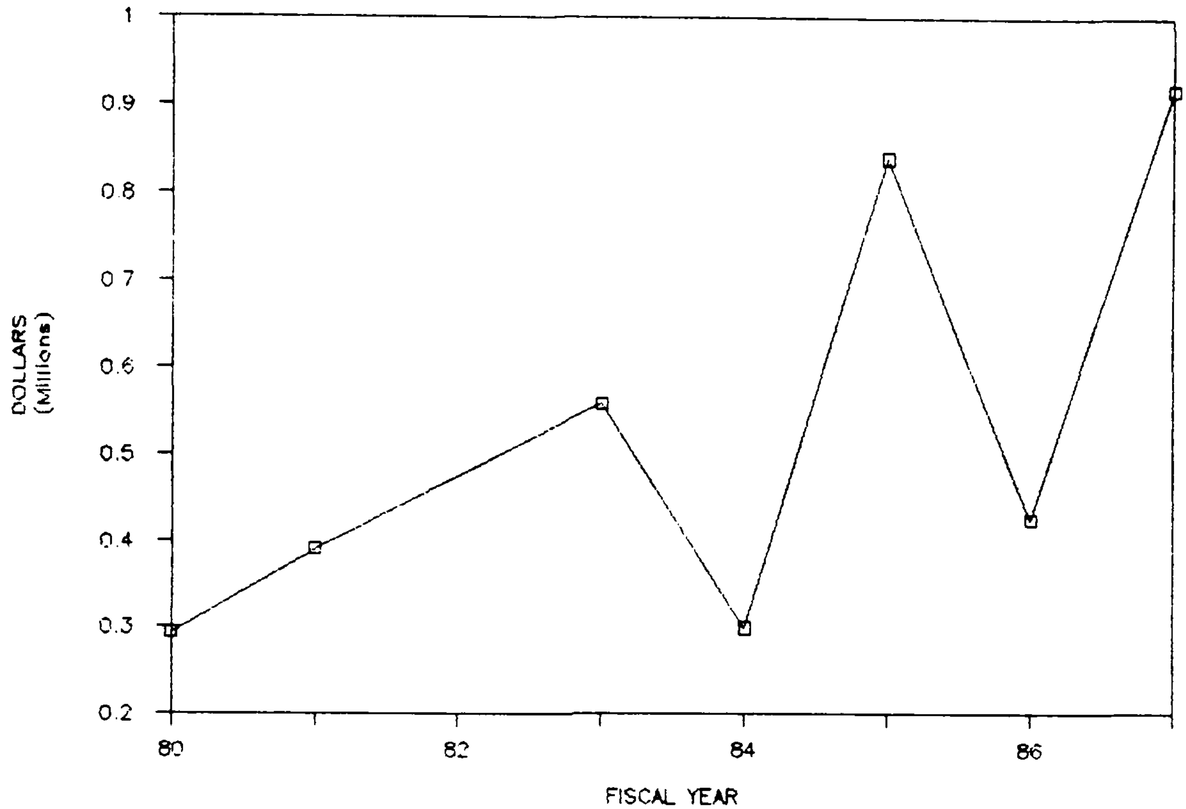

Figure 9. Annual spending for roadways—Ft. Richardson.

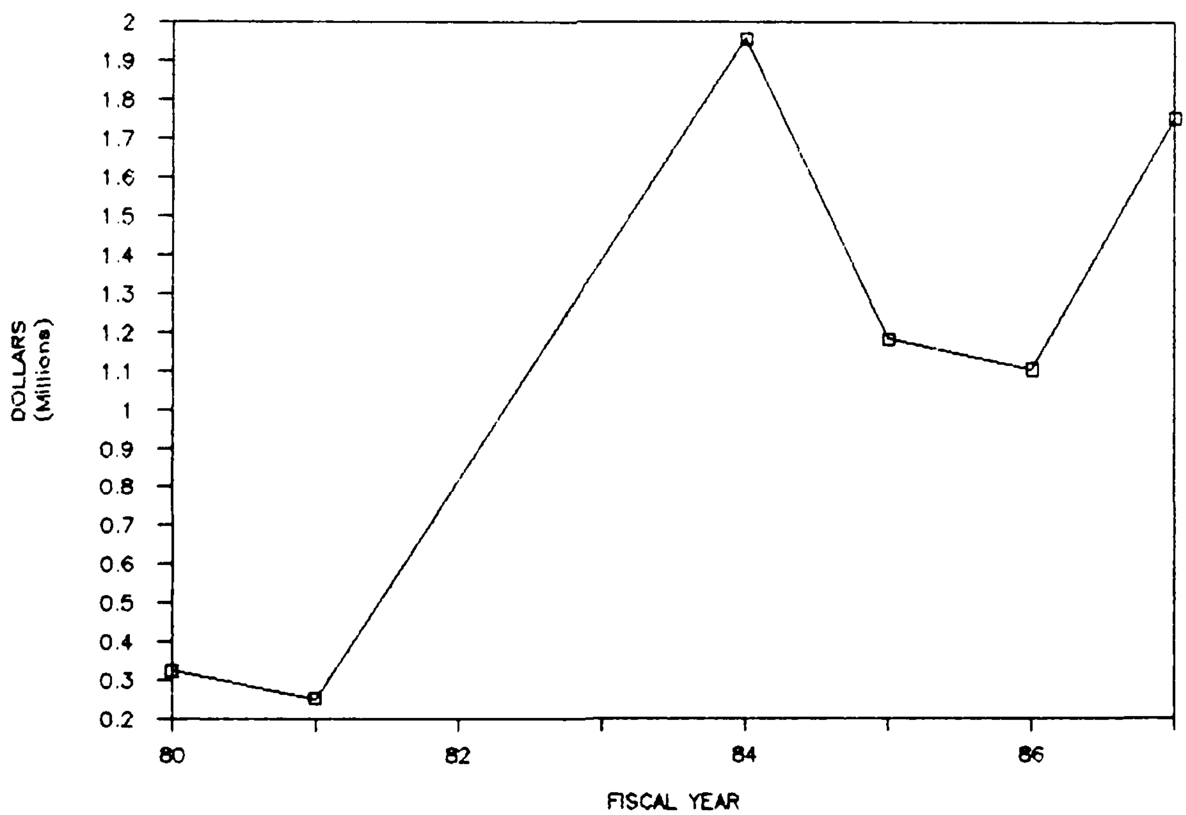

Figure 10. Annual spending for roadways—Ft. Belvoir.

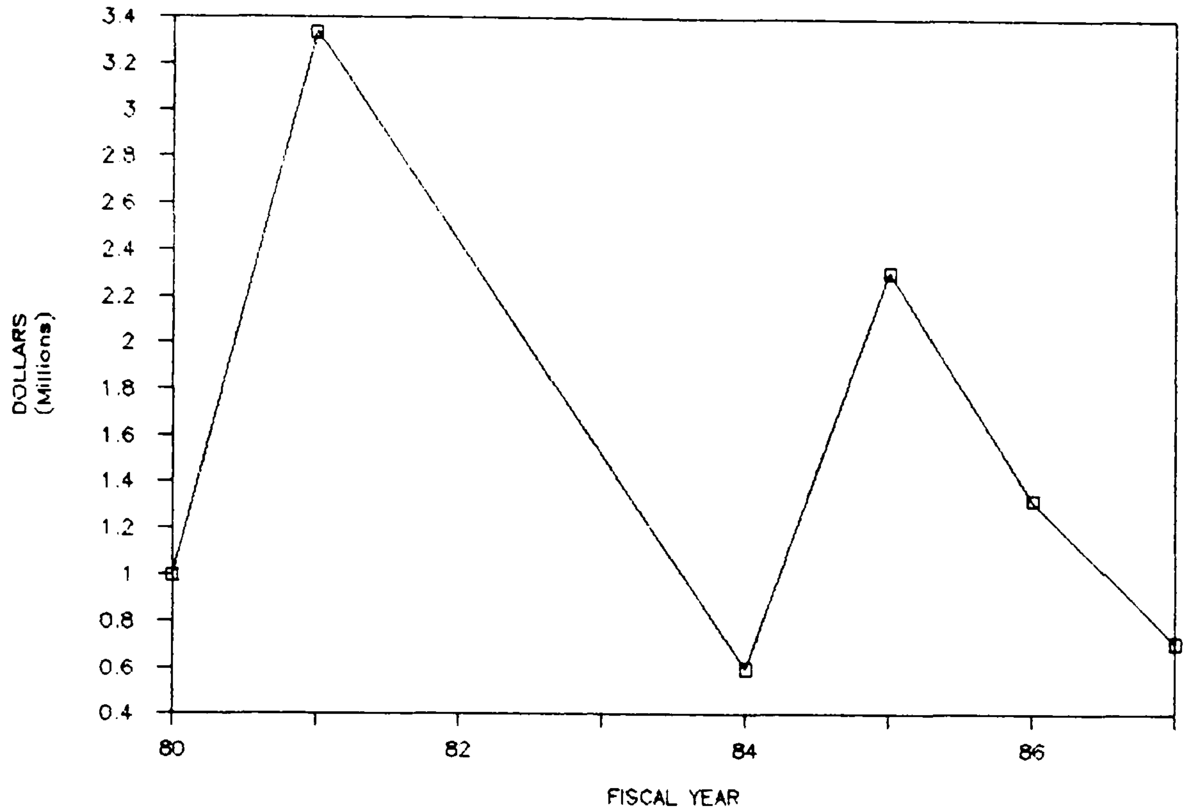

Figure 11. Annual spending for roadways-Ft. Benning.

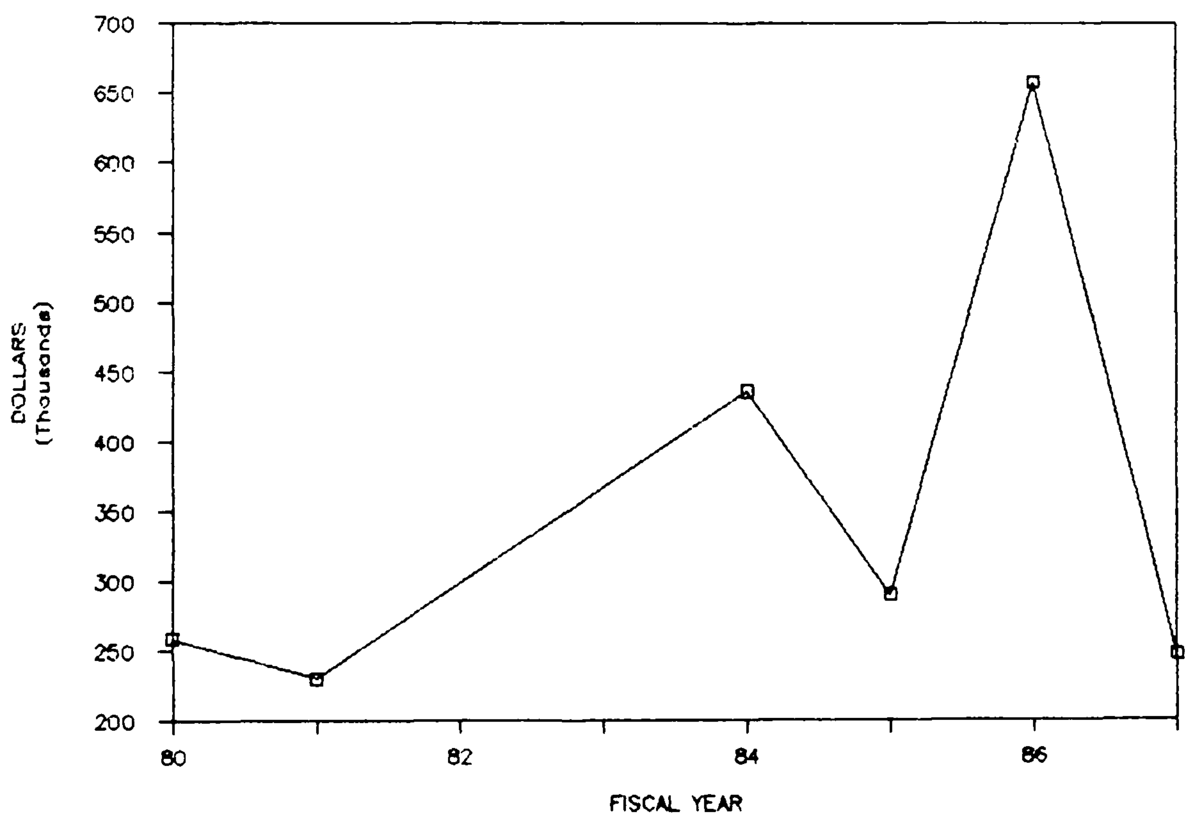

Figure 12. Annual spending for roadways-Ft. Jackson.

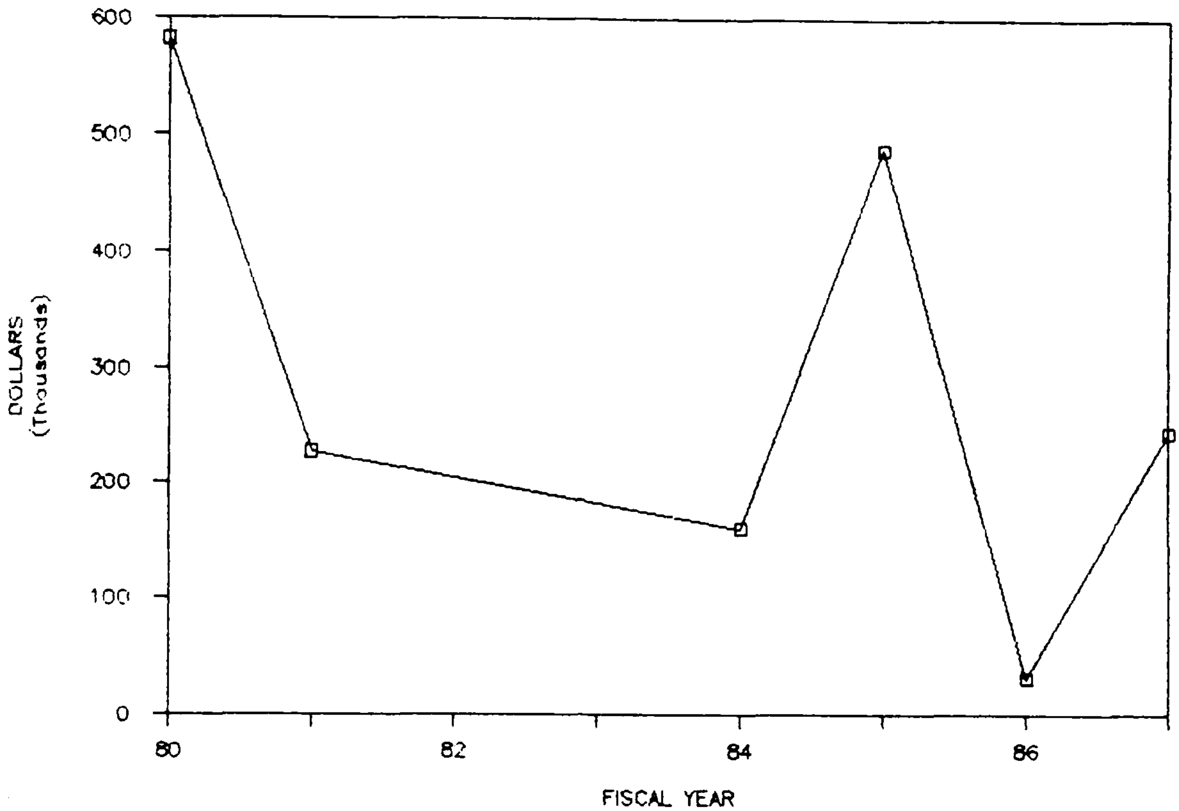

Figure 13. Annual spending for roadways—Ft. Lee.

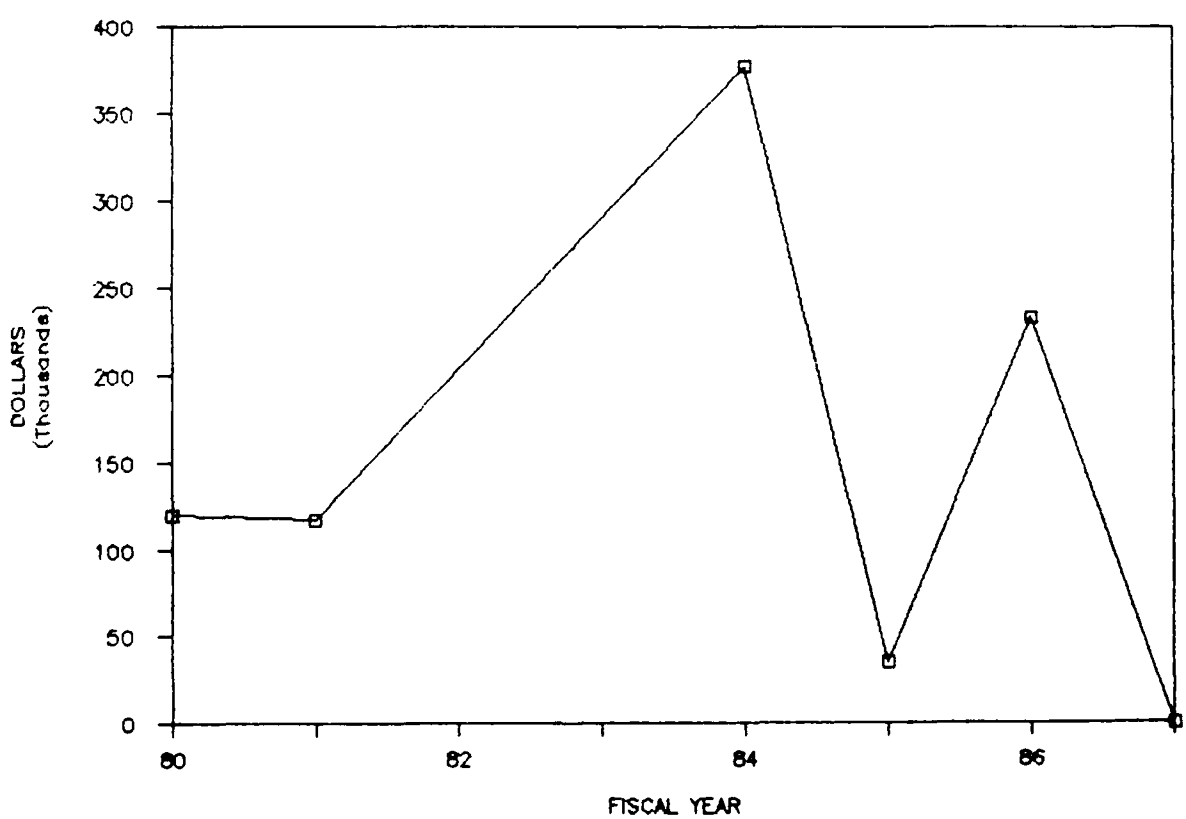

Figure 14. Annual spending for roadways—Ft. Pickett.

3 ANALYSIS OF PAVER AND RED BOOK DATA

PAVER system data, provided by USACERL, consisted of sectional PCI data for each of the FORSCOM, TRADOC, and AMC installations for which PAVER is currently implemented. For each section, data was provided on section area in square yards (SY), section rank (primary, secondary, tertiary), section type (asphaltic concrete, portland cement concrete), construction date, last inspection date, and PCI at the last inspection date. For each installation, these data were processed to determine weighted averages (based on section area) for: pavement age, rate of deterioration, PCI at last inspection; and, the projected 1989 PCI. The deterioration rate was calculated by subtracting the PCI at last inspection from an assumed initial PCI of 100 and dividing the result by the pavement age to determine the decrease in PCI points per year. The projected 1989 PCI was determined based on the deterioration rate and the PCI at last inspection. Pavements having a PCI of 100 at the date of last inspection were assigned a deterioration rate of 3 points/year based on PAVER system guidelines. The data were processed once including pavements of all ranks, and once including only primary rank pavements. These two data sets were analyzed separately.

Based on examination of the data, and by trial and error, it was determined that several error conditions could exist in the data. These conditions were:

a. Missing construction or inspection date
b. PCI not equal to 100 for pavement of zero age
c. Construction date occurring after inspection date.

When data containing these errors occurred, the data was rejected from further processing.

The Red Book data was also subjected to processing prior to being combined with the PAVER system data for analysis. The Red Book data as received was partitioned into databases by year. These yearly databases were combined into one large database containing only data for the K5110 activity. From this database small files were exported for each installation. These files were then processed to determine for each installation the average annual pavement area in thousands of square yards (KSY), the average annual cost for maintenance, and the average annual unit cost for maintenance. The average annual unit cost was calculated in reported dollars and, corrected for inflation, in 1980 dollars. This data, and data for FY87, were merged with the PAVER system data. The merged data matrices for all pavement ranks and pavement of primary rank are included in Appendix A.

Data Analysis - Pavement of All Ranks

Table 6 below contains the data nomenclature used in the analysis. Since a primary goal of this work effort was to evaluate the relationship between the PAVER system data and the Red Book data, correlations were developed among all the PAVER and Red Book variables. This correlation matrix is shown in Table 7.

Table 6. Nomenclature

SY	- Installation square yardage from PAVER system
ACSY	- Square yardage of asphaltic concrete, from PAVER system
PCSY	- Square yardage of Portland cement concrete, from PAVER system
AGE	- Average pavement age at last inspection, based on PAVER system data
IPCI	- Average PCI at last inspection, based on PAVER system data
PCI89	- Average projected 1989 PCI based on PAVER system data
DRATE	- Average pavement deterioration rate points/yr, based on PAVER system data
RKSY	- Installation square yardage in thousands, from Red Book data
CAV	- Installation average annual pavement maintenance cost in dollars based on Red Book data
UCAV	- Installation average annual unit cost in dollars per thousand square yards for pavement maintenance, based on Red Book data
UCADJ	- Installation average annual unit cost in 1980 dollars per thousand square yards, adjusted regionally using AR415-17 factors.
KS87	- Installation square yardage for 1987 in thousands, from Red Book
UC87	- Installation unit cost for pavement maintenance in 1987 dollars per thousand square yards.

Examination of the correlation matrix in Table 7 indicates significant correlations between the Red Book installation square yardage and the average annual maintenance cost; between the adjusted average annual unit cost and pavement age; and, between the deterioration rate and average annual maintenance cost and adjusted average annual unit cost.

The relationship between square yardage and average annual maintenance cost is positive, meaning that larger installations tend to have larger overall pavement maintenance costs. Another correlation, not as strongly significant, is a negative correlation between unit costs and installation square yardage, indicating that larger installations may benefit from economies of scale.

The negative correlation observed between age and the adjusted average annual unit cost would indicate that, when inflation and regional differences are eliminated, installations with older pavements tend to have lower unit costs for pavement maintenance.

The positive correlation between deterioration rate and average annual cost and adjusted average annual unit cost suggests that installations having higher pavement deterioration rates have higher costs. Also, although nonsignificant, the negative correlation between deterioration rate and age suggests that installations with older pavements have lower deterioration rates.

Finally, the largest correlation between PCI and any cost variable was between PCI and the 1987 unit cost. Since most of the PCI data was gathered during the 1986 to 1987 time frame, this tends to indicate that the PCI data is most closely related to current costs.

Table 7. Correlation Matrix For Pavement of All Ranks
FORSCOM, TRADOC, and AMC

Correlations:	SY*	ACSY	PCSY	AGE	IPCI	PCI89
SY	1.0000	.9881**	.6399**	.0747	-.1854	-.1581
ACSY	.9881**	1.0000	.6117**	.0372	-.1623	-.1449
PCSY	.6399**	.6117**	1.0000	.2012	-.2836	-.3036
AGE	.0747	.0372	.2012	1.0000	-.2948	-.0826
IPCI	-.1854	-.1623	-.2836	-.2948	1.0000	.8940**
PCI89	-.1581	-.1449	-.3036	-.0826	.8940**	1.0000
DRATE	.1229	.1083	.2083	-.3080	-.3167	-.5326**
RKSY	.6456**	.6464**	.4937*	-.1118	-.1933	-.1641
CAV	.5642**	.5824**	.4835*	-.3458	.0428	-.0537
UCAV	-.1412	-.1171	-.0412	-.1965	.2931	.1470
UCADJ	-.1316	-.1145	-.0029	-.4438*	.2904	.1002
KS87	.5046*	.4956*	.3915	-.1502	-.1858	-.1209
UC87	-.1769	-.1672	-.1505	-.1048	.4059	.3833

	DRATE	RKSY	CAV	UCAV	UCADJ	KS87	UC87
SY	.1229	.6456**	.5642**	-.1412	-.1316	.5046*	-.1769
ACSY	.1083	.6464**	.5824**	-.1171	-.1145	.4956*	-.1672
PCSY	.2083	.4937*	.4835*	-.0412	-.0029	.3915	-.1505
AGE	-.3080	-.1118	-.3458	-.1965	-.4438*	-.1502	-.1048
IPCI	-.3167	-.1933	.0428	.2931	.2904	-.1858	.4059
PCI89	-.5326**	-.1641	-.0537	.1470	.1002	-.1209	.3833
DRATE	1.0000	.0383	.4219*	.3801	.4565*	-.0586	.0414
RKSY	.0383	1.0000	.6454**	-.3748	-.2717	.9456**	-.3158
CAV	.4219*	.6454**	1.0000	.3127	.3991*	.5359*	.2552
UCAV	.3801	-.3748	.3127	1.0000	.9051**	-.4578*	.6212**
UCADJ	.4565*	-.2717	.3991*	.9051**	1.0000	-.3382	.4841*
KS87	-.0586	.9456**	.5359*	-.4578*	-.3382	1.0000	-.3120
UC87	.0414	-.3158	.2552	.6212**	.4841*	-.3120	1.0000

Minimum pairwise N of cases: 29 Significance: * - .01 ** - .001

Significance - a correlation is indicated as being significant at either the 99% (*), or the 99.9% (**) confidence level. These confidence levels indicate the probability that the correlation observed is exceptional, as opposed to arising from random variation.

*1 sq yd = .8361 m^2.

Aside from the relationship between PCI and 1987 unit costs, the next largest correlation coefficient for PCI is between PCI and deterioration rate. This negative correlation, while not highly significant, tends to indicate that installations having low average PCI have higher pavement deterioration rates.

Scatterplots for some of the relationships discussed above are shown below.

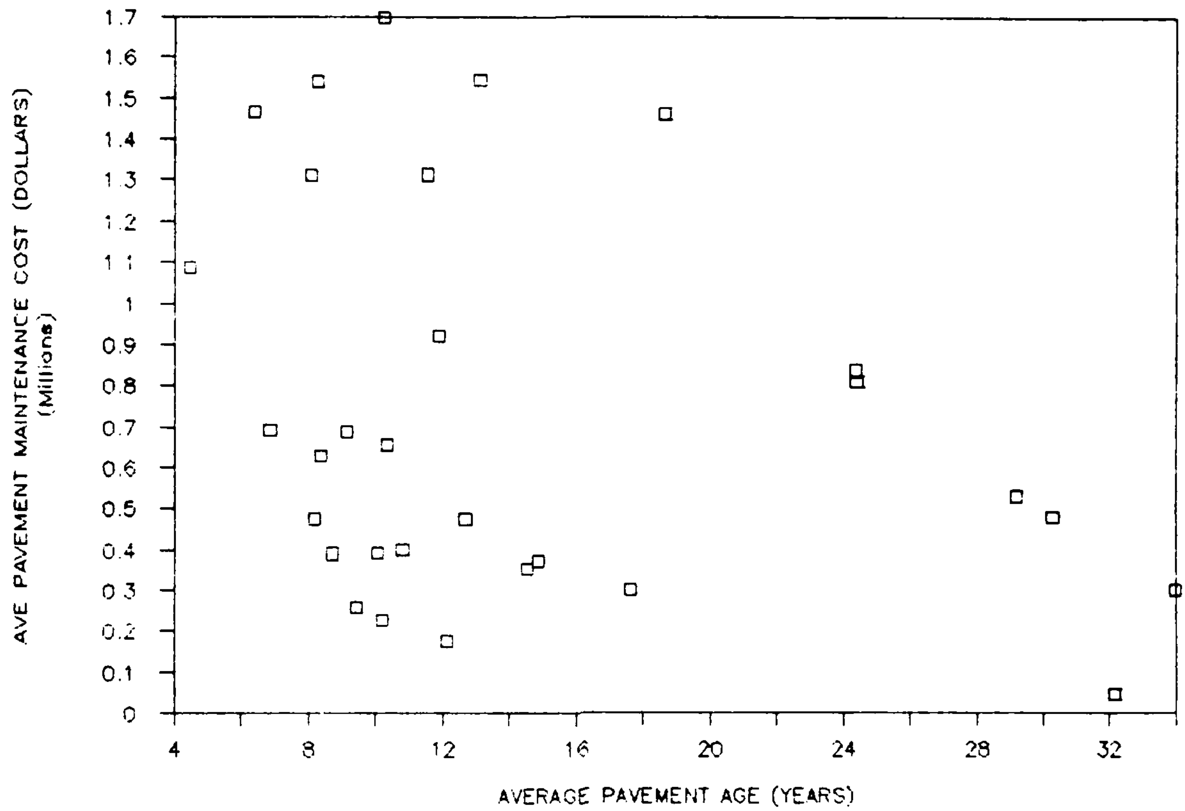

Figure 15. Average Red Book pavement maintenance cost.

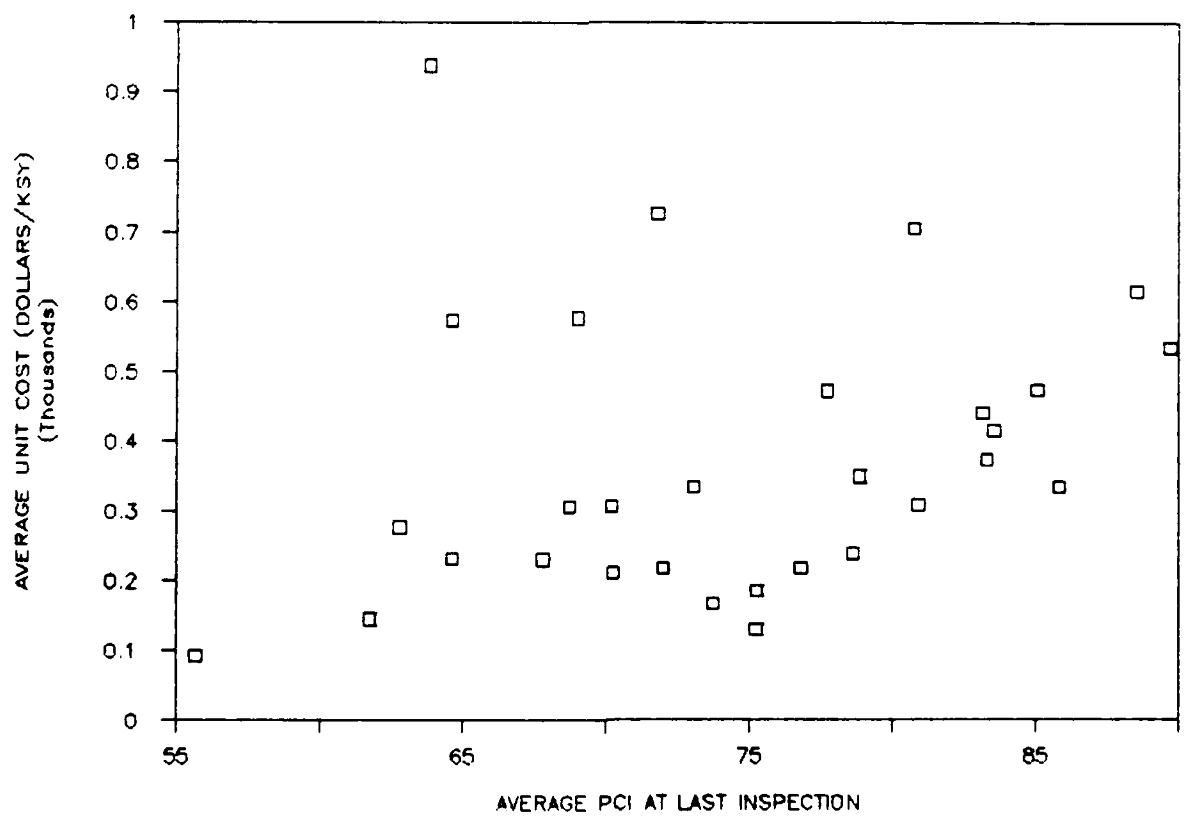

Figure 16. Average Red Book unit cost.

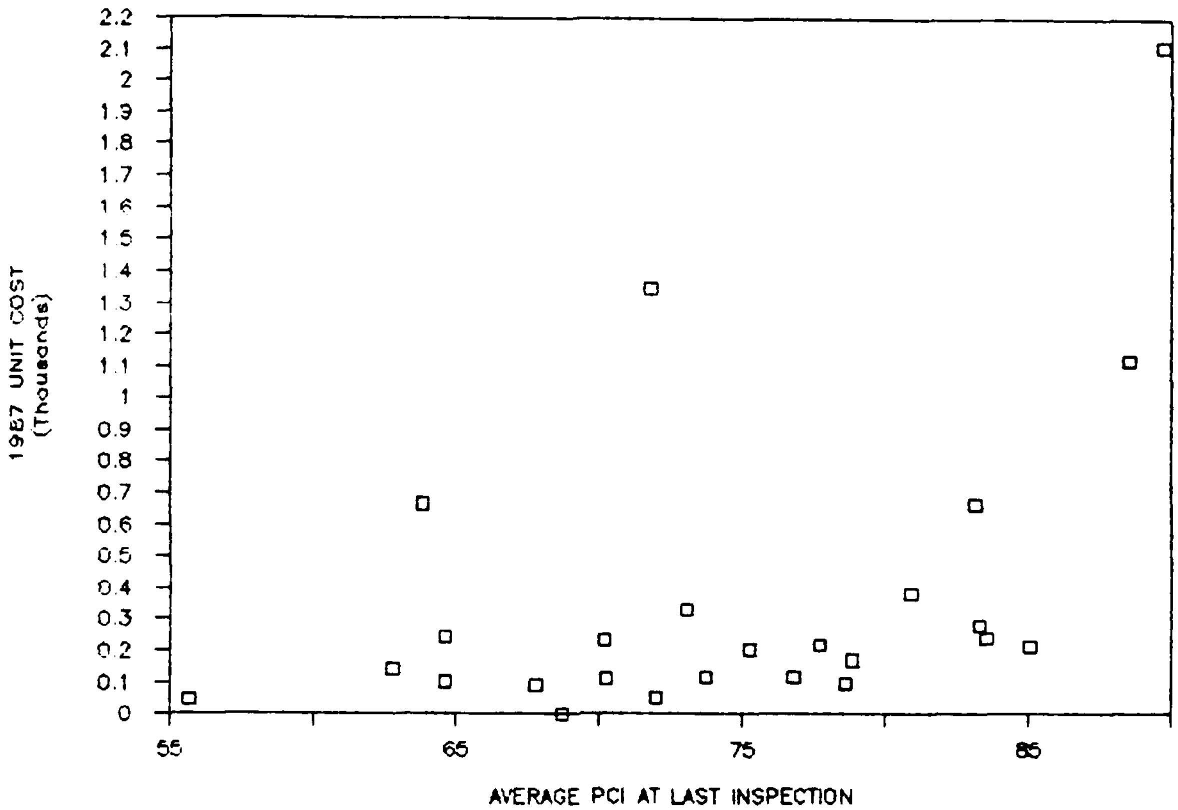

Figure 17. Average PCI at last inspection by 1987 unit cost.

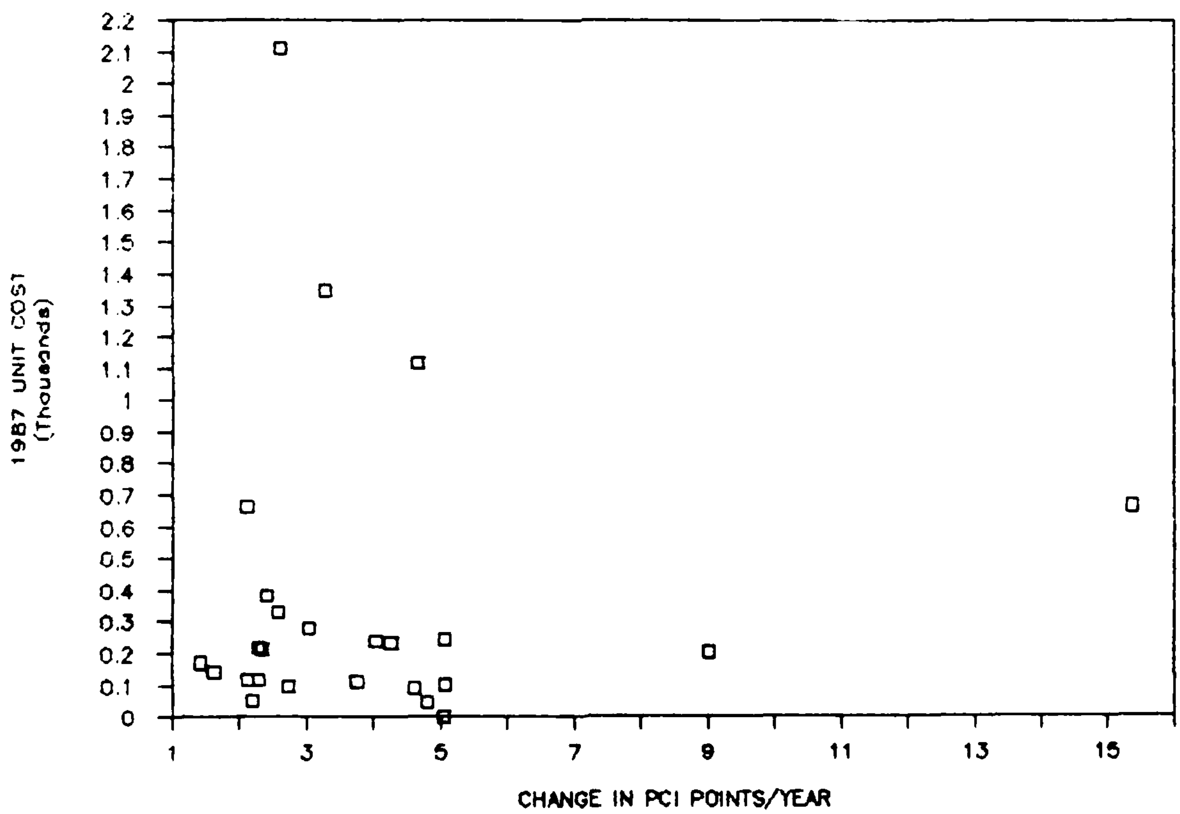

Figure 18. Deterioration rate by 1987 unit cost.

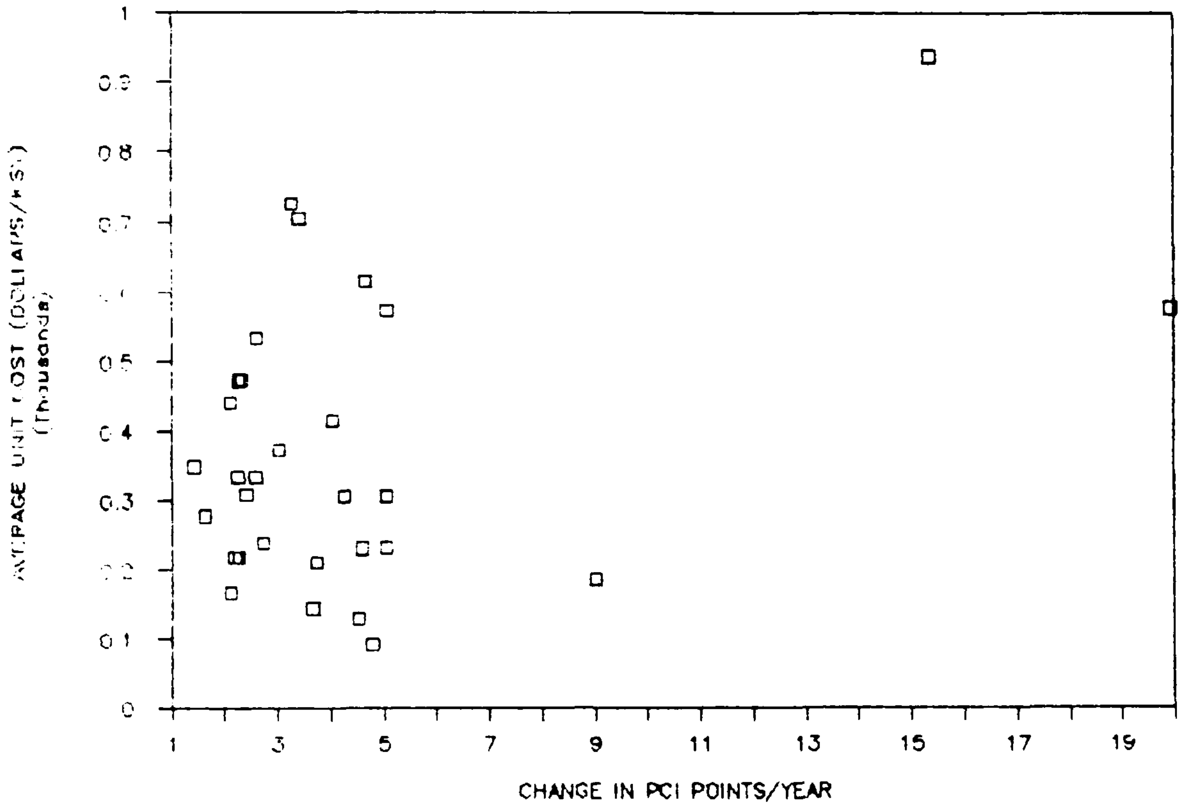

Figure 19. Deterioration rate by average Red Book unit cost.

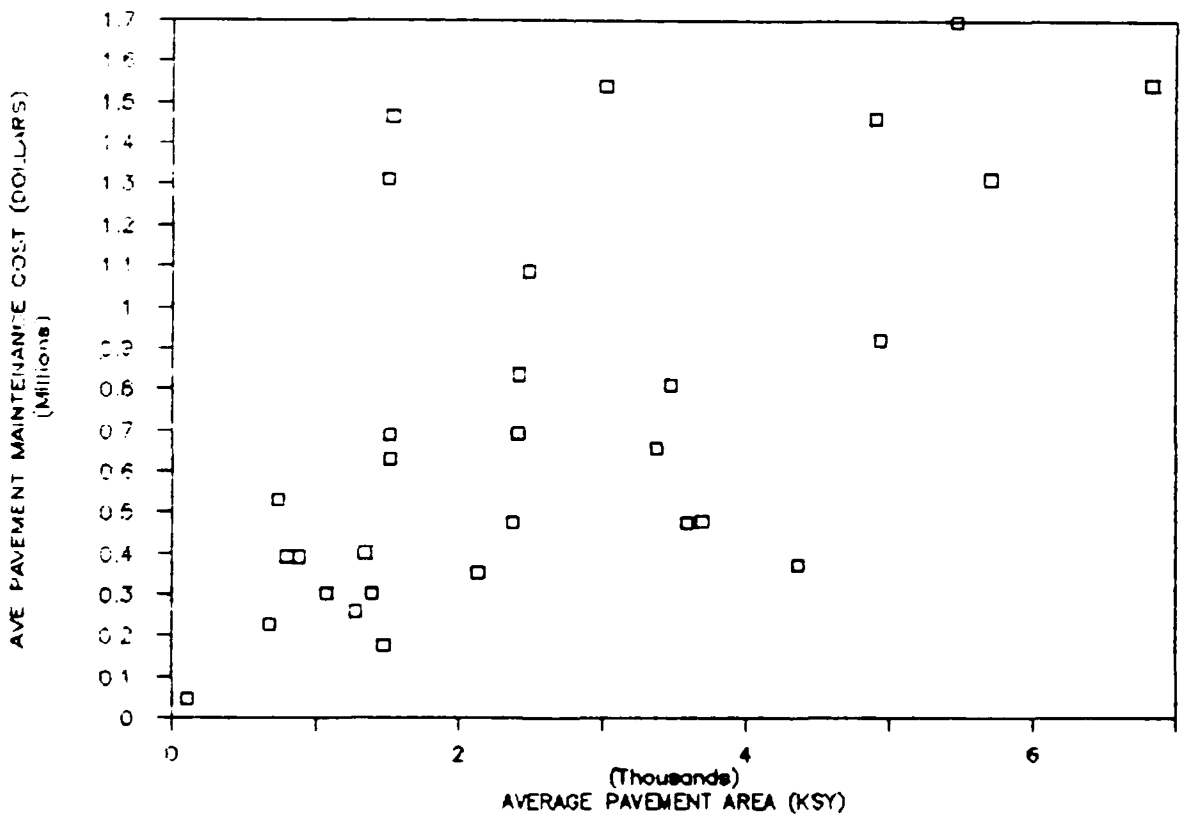

Figure 20. Average pavement area by average Red Book pavement maintenance cost.

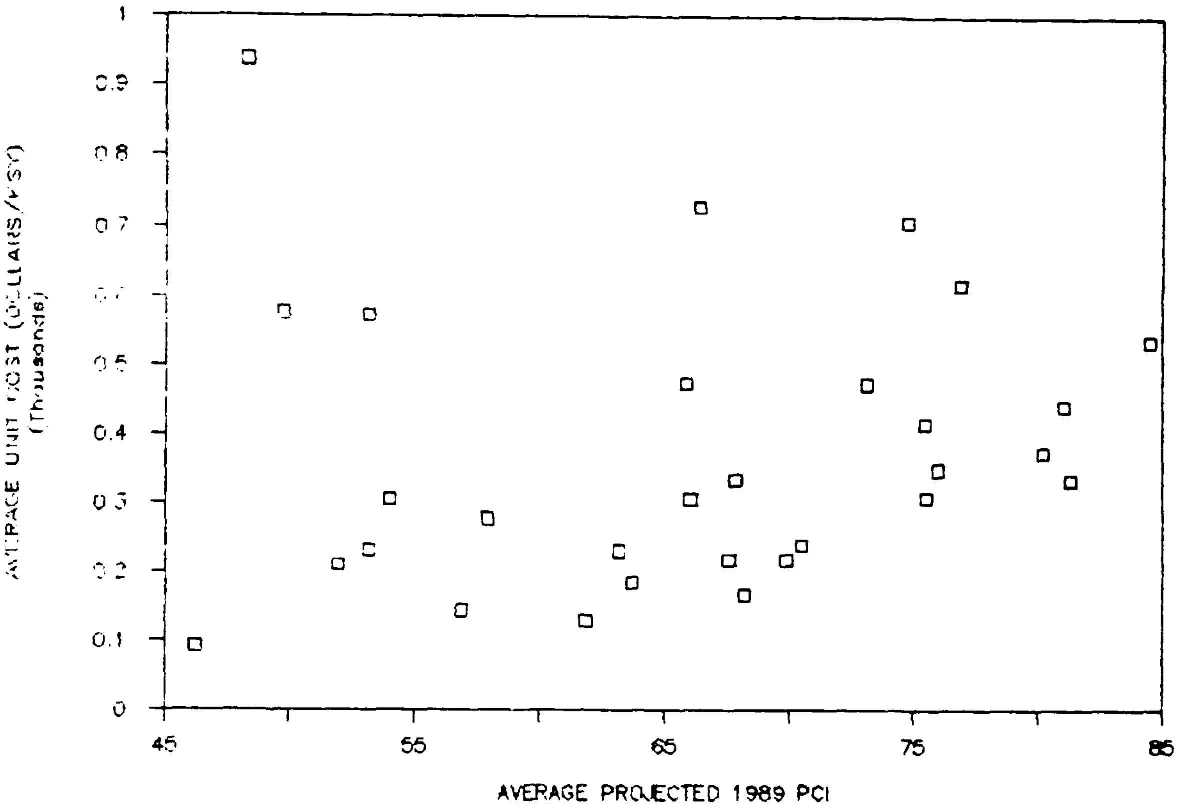

Figure 21. Projected 1989 PCI by average Red Book unit cost.

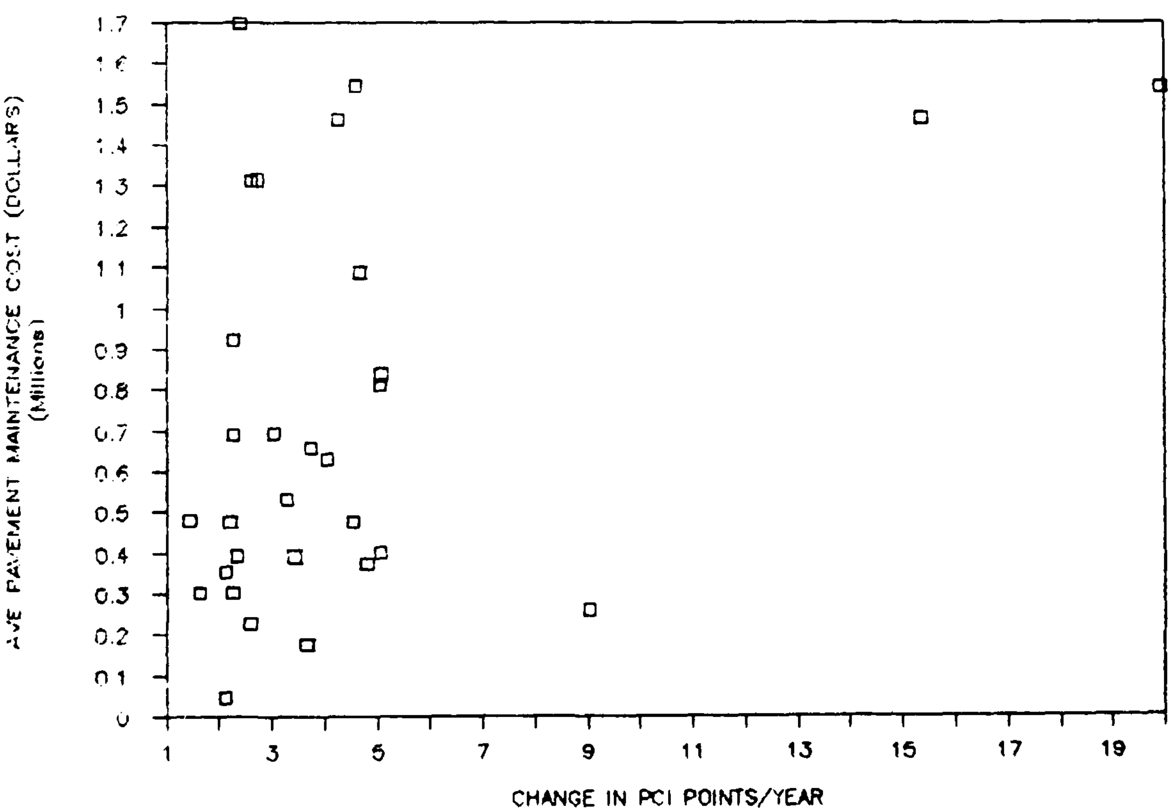

Figure 22. Deterioration rate by average Red Book pavement maintenance cost.

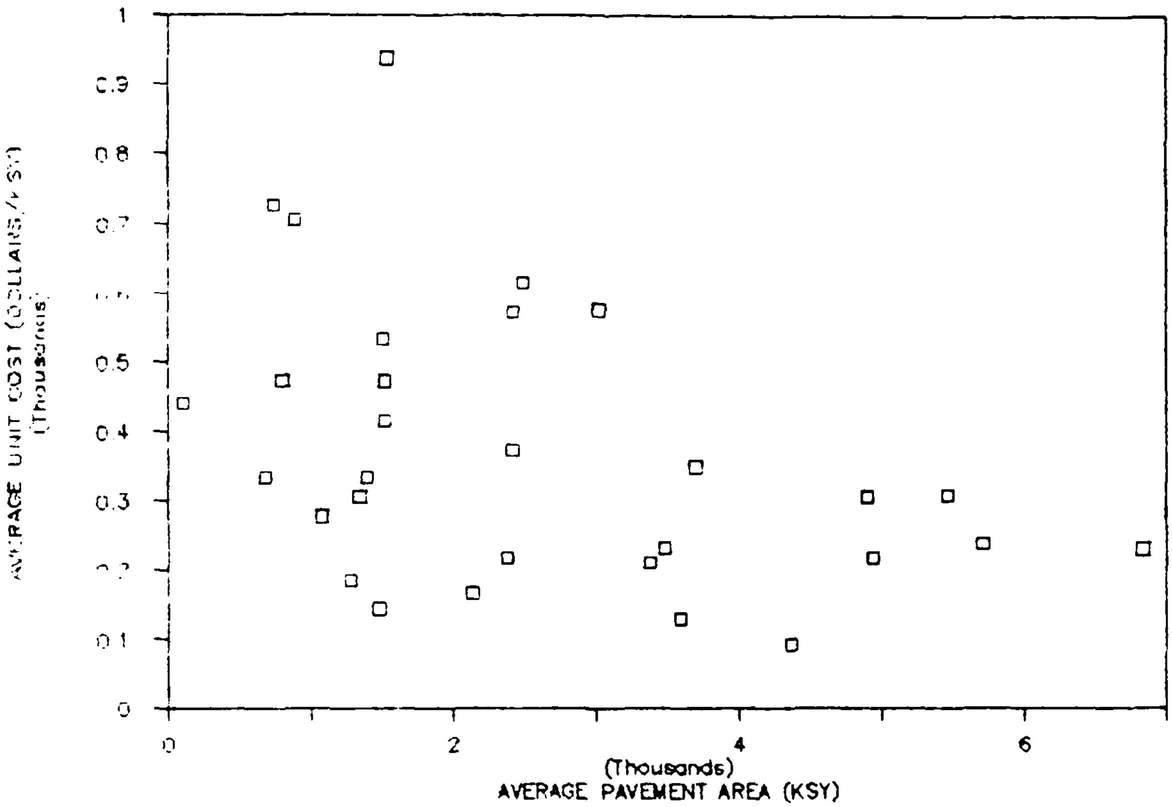

Figure 23. Average pavement area by average Red Book unit cost.

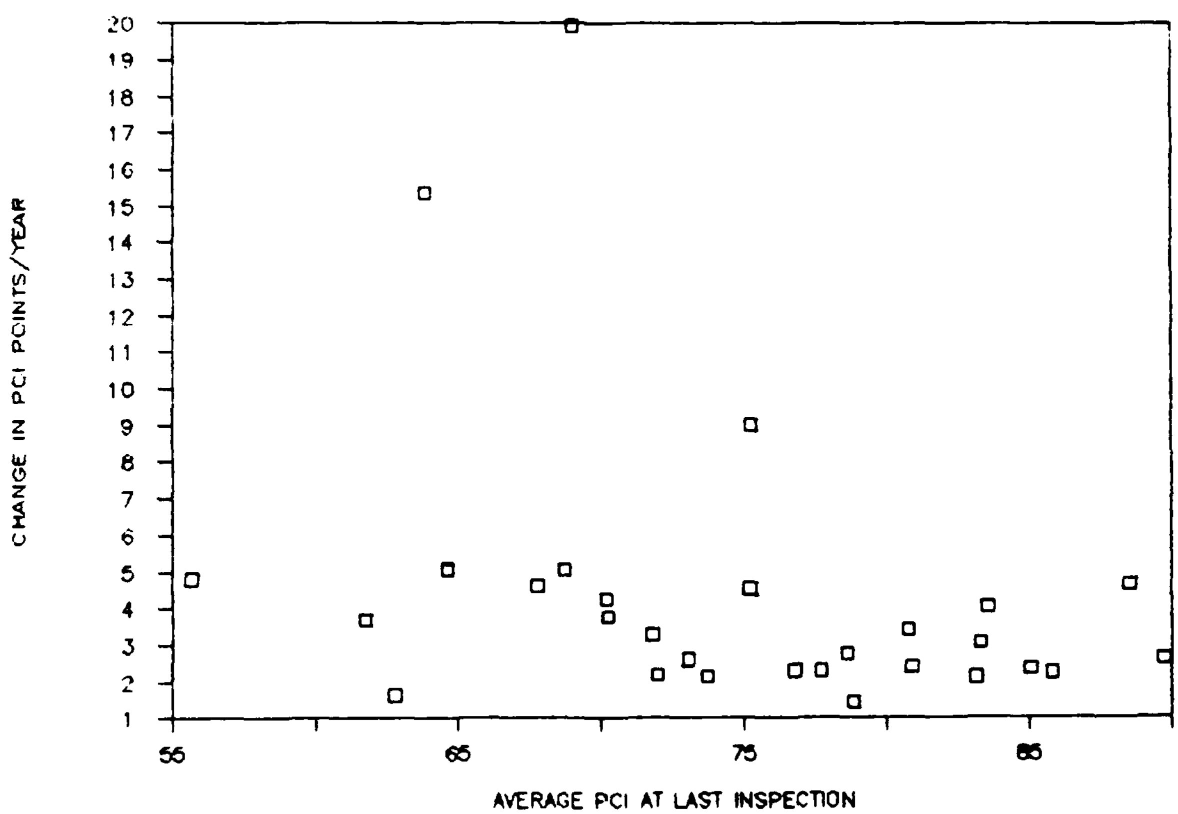

Figure 24. Deterioration rate by average PCI at last inspection.

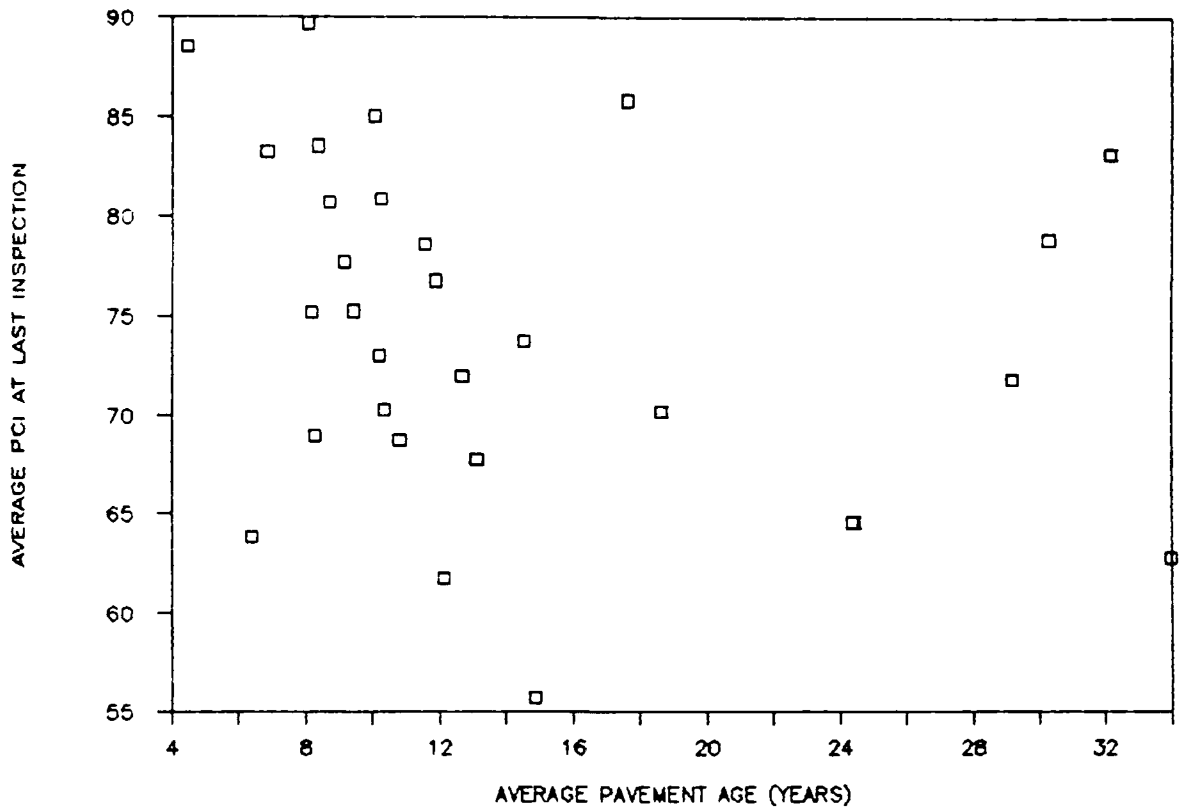

Figure 25. Average pavement age by average PCI at last inspection.

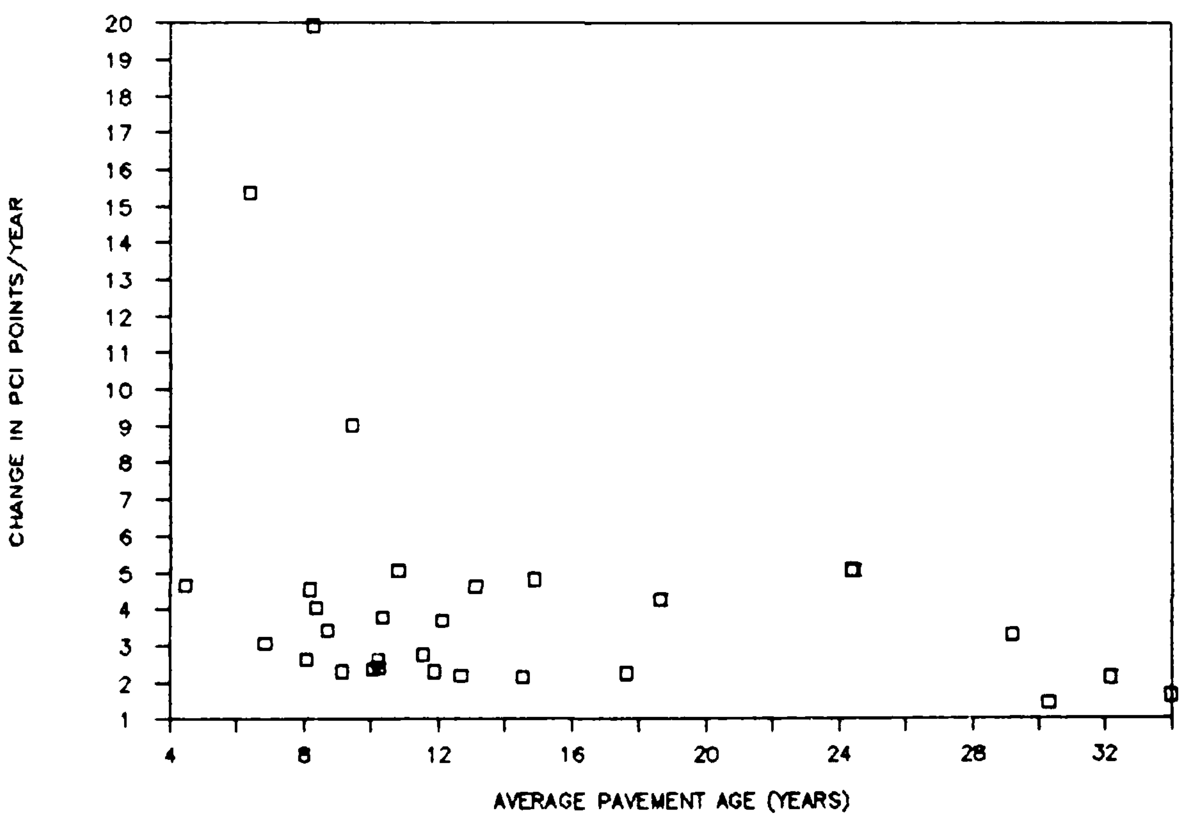

Figure 26. Average pavement age by deterioration rate.

Correlations were also determined with the data partitioned by major command. The results for FORSCOM installations were in most cases the same as for both commands combined. The TRADOC correlations however, where quite different from the combined results.

The TRADOC results indicated a much higher degree of correlation between the PCI variables and the Red Book cost variables. The TRADOC correlation matrix indicates significant correlations between PCI and average annual unit cost, adjusted average annual unit cost, and 1987 unit cost. The positive correlation between PCI and cost data suggests that TRADOC installations with higher pavement maintenance costs have higher PCIs. The highest correlation obtained, 0.9599 between PCI and 1987 unit cost, suggests as for FORSCOM and the combined data, that the greatest correlation between PCI and costs occurs for current costs. A scatterplot of this data is shown in Figure 27.

Significant correlations for TRADOC data also occur between square yardage of Portland cement concrete and average annual cost, and between average annual cost and Red Book square yardage. Unlike the FORSCOM data, no significant correlation occurred for deterioration rate, and unlike the combined data, no significant correlation occurred between age and adjusted average unit costs. The positive correlation between installation square yardage and average annual costs indicates that, as in the combined data, larger installations have greater pavement management costs. The additional correlation between square yardage of portland cement concrete and average annual cost, suggests that TRADOC installations having greater amounts of Portland cement concrete pavement have higher pavement maintenance costs.

Few significant correlations were observed for the AMC data, to some extent due to the small number (4) of installations for which data was available. Correlations similar to FORSCOM, TRADOC, and the combined data set, were observed. Correlations were observed between PCI and cost data, and between deterioration rate and cost data. Correlations were also observed between age and adjusted average annual unit cost which suggested that unit costs were lower for installations with older pavement.

Complete correlation matrices for FORSCOM, TRADOC, and AMC data are included in Appendix B.

Data Analysis - Primary Rank Pavement

PAVER data was processed to select those pavements of primary rank. This data was then averaged and merged with the annually averaged Red Book data as in the previous analysis. A correlation matrix was calculated for this data and is shown in Table 8.

Examination of the correlation matrix for primary pavement revealed the same trends with regard to sign of the correlations as was observed in the correlation matrix for pavement of all ranks. The strength of the correlations was generally lower for all variables. Because the general pattern of correlation was the same for the primary rank matrix and the matrix for all ranks, no scatterplots were generated.

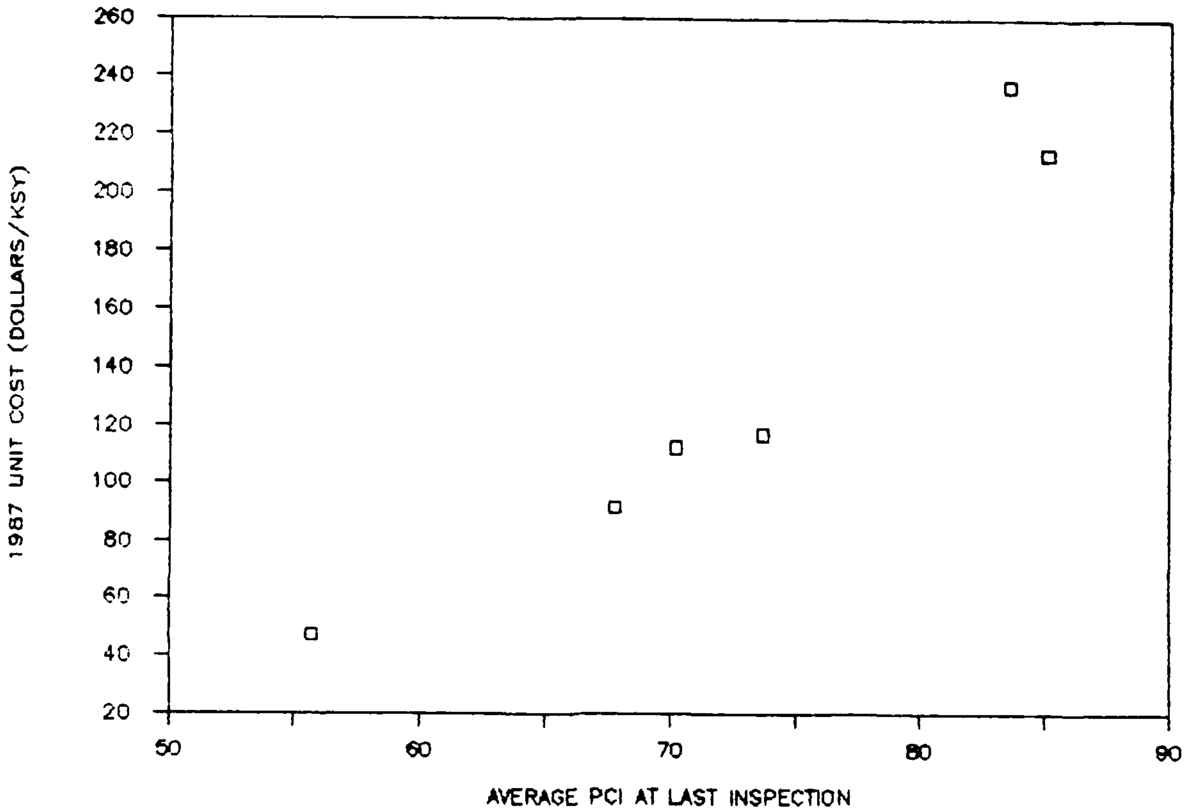

Figure 27. Average PCI at last inspection by 1987 unit cost for TRADOC installations.

The primary rank data set was also partitioned into FORSCOM and TRADOC data sets. Again the correlations for the FORSCOM data were in most cases similar to those of the combined data set. However, the FORSCOM primary rank data showed significant positive correlation between the area of Portland cement concrete and deterioration rate, and, a significant negative correlation between age and PCI, which were not seen for the "all pavements, FORSCOM only" data.

The TRADOC data again showed a much higher degree of correlation in the same manner as observed for the all rank data set, and, in addition, indicated a significant negative correlation between PCI and deterioration rate.

Because only three AMC installations in this sample had primary rank pavement, no useful correlations could be obtained for the AMC primary rank data.

Complete correlation matrices for the FORSCOM and TRADOC data are included in Appendix B.

Table 8. Correlation Matrix For Primary Pavements
FORSCOM, TRADOC, and AMC

Correlations:	SY	ACSY	PCSY	AGE	IPCI	PCI89
SY	1.0000	.9824**	.6175**	.0754	-.3444	-.3693
ACSY	.9824**	1.0000	.5803**	.0615	-.3273	-.3527
PCSY	.6175**	.5803**	1.0000	.0773	-.2784	-.2679
AGE	.0754	.0615	.0773	1.0000	-.3382	-.1226
IPCI	-.3444	-.3273	-.2784	-.3382	1.0000	.8896**
PCI89	-.3693	-.3527	-.2679	-.1226	.8896**	1.0000
DRATE	.3726	.3527	.3428	-.2663	-.2860	-.5217**
RKSY	.6888**	.6714**	.5983**	.0514	-.3583	-.3153
CAV	.6486**	.6763**	.5431**	-.1706	-.1256	-.1687
UCAV	-.1168	-.0709	-.1052	-.0854	.1430	.0666
UCADJ	-.0260	.0012	-.0049	-.3123	.1366	-.0064
KS87	.6155**	.5564*	.5438*	.0122	-.3705	-.2957
UC87	-.2163	-.1981	-.2122	-.1151	.2950	.2945

	DRATE	RKSY	CAV	UCAV	UCADJ	KS87	UC87
SY	.3726	.6888**	.6486**	-.1168	-.0260	.6155**	-.2163
ACSY	.3527	.6714**	.6763**	-.0709	.0012	.5564*	-.1981
PCSY	.3428	.5983**	.5431**	-.1052	-.0049	.5438*	-.2122
AGE	-.2663	.0514	-.1706	-.0854	-.3123	.0122	-.1151
IPCI	-.2860	-.3583	-.1256	.1430	.1366	-.3705	.2950
PCI89	-.5217**	-.3153	-.1687	.0666	-.0064	-.2957	.2945
DRATE	1.0000	.1446	.3835	.2477	.3834	.1719	-.0772
RKSY	.1446	1.0000	.6497**	-.3571	-.2459	.9457**	-.3099
CAV	.3835	.6497**	1.0000	.3237	.4206*	.5366*	.2574
UCAV	.2477	-.3571	.3237	1.0000	.9006**	-.4488*	.6257**
UCADJ	.3834	-.2459	.4206*	.9006**	1.0000	-.3246	.4927*
KS87	.1719	.9457**	.5366*	-.4488*	-.3246	1.0000	-.3073
UC87	-.0772	-.3099	.2574	.6257**	.4927*	-.3073	1.0000

Minimum pairwise N of cases: 27 Significance: * - .01 ** - .001

Data Analysis - Sierra AD

In addition to the analysis of FORSCOM, TRADOC, and AMC data, a more detailed analysis of PAVER and Red Book data for Sierra Army Depot was also performed. Unlike the previous data, the Sierra data provided an opportunity to evaluate PAVER data for multiple inspection years. It was hoped that analysis of this data would better reveal the relationship between maintenance expenditures and pavement quality.

The Sierra data are summarized in Table 9. As in the previous analysis, the data was examined for pavement of all ranks and for primary rank pavement only. Because PCI data was gathered through inspections over several years, a slightly different set of variables was used in the analysis of the Sierra data. The definitions of these variables are as follows:

Year - Fiscal year

IPCI - Weighted average PCI for pavement inspected in a given fiscal year

INSY - Square yards of pavement inspected in a given fiscal year

COST - Total Red Book K5110 dollars reported for a given fiscal year

KSY - Total square yards of pavement at Sierra as reported in the Red Book for a given fiscal year, in thousands

SYINPC - Square yardage of pavement whose PCI increased in a fiscal year

PCISY - The product of the change in PCI and square yardage for all sections whose PCI increased in a fiscal year, summed over all sections

CONSTR - The square yardage of new pavement constructed in a fiscal year, as determined from PAVER inspection data

SUMCR - The sum of the square yardage constructed and the square yardage whose PCI increased in a given fiscal year

Table 9. Sierra AD PAVER and Red Book Data

ALL PAVEMENTS

YEAR	IPCI	INSY	COST	KSY	SYPCIN	PCISY	CONSTR	SUMCR
1983	85.96	752687	358764	1619	0	0	255330	255330
1984	72.45	1747336	320069	1619	131554	3080094	64886	196440
1985	86.19	265999	1404491	2316	60467	1113802	2962	63429
1986	77.81	616693	638294	2316	172173	1509334	61118	233291
1987	75.29	682724	1932219	1621	173898	2726296	14155	188053
1988	74.26	688262			326977	5676464	26302	353279

PRIMARY PAVEMENTS

YEAR	IPCI	INSY	COST	KSY	SYPCIN	PCISY	CONSTR	SUMCR
1983	86.44	411692	358764	1619	0	0	77412	77412
1984	79.87	230243	320069	1619	70935	1688415	13257	84192
1985	82.34	105266	1404491	2316	14829	189221	0	14829
1986	74.82	197198	638294	2316	42391	254051	1142	43533
1987	76.75	159121	1932219	1621	15454	173424	2357	17811
1988	73.01	238886			83575	1092659	492	84067

The approach taken in the analysis of the Sierra data was to examine data elements which should be directly related to the costs of pavement maintenance. As before, IPCI, the inspection PCI, was considered. In addition, because multiple inspections occurred, it was possible to calculate the square yardage of pavement whose PCI increased in a given fiscal year, and also, the square yardage of new pavement constructed in a fiscal year. These two variables were expected to be directly related to maintenance expenditures. Also, in order to include consideration of the amount in which a section's PCI increased, the variable PCISY was developed by taking the product of the section square yardage and its change in PCI. A correlation analysis was performed to examine the relationships between these PAVER-based data elements and Red Book cost data for Sierra AD. The results are shown in Table 10, as Case 1, Case 2, and Case 3.

Case 1, in Table 10, shows the correlation between Red Book costs and PAVER data elements for pavement of all ranks at Sierra. None of the correlations are high enough to be significant given the small number of data points (5). The greatest correlation is -.6496 between cost and square yardage constructed, and is opposite in sign of what would be expected to occur. That is, we would expect Red Book costs to be higher for fiscal years when new pavement was constructed, not lower.

Table 10. Correlation Matrix for Sierra AD Data

CASE 1:

Correlations:	IPCI	INSY	COST	KSY	SYINPC	PCISY	CONSTR	SUMCR
IPCI	1.0000	-.7022	.0032	.3582	-.8266	-.9163	.4045	-.2867
INSY	-.7022	1.0000	-.5515	-.6125	.1984	.5837	.1314	.3817
COST	.0032	-.5515	1.0000	.1186	.3355	.2642	-.6496	-.5485
KSY	.3582	-.6125	.1186	1.0000	.1061	-.2731	-.4278	-.4780
SYINPC	-.8266	.1984	.3355	.1061	1.0000	.7920	-.6857	.0779
PCISY	-.9163	.5837	.2642	-.2731	.7920	1.0000	-.6637	-.1034
CONSTR	.4045	.1314	-.6496	-.4278	-.6857	-.6637	1.0000	.6722
SUMCR	-.2867	.3817	-.5485	-.4780	.0779	-.1034	.6722	1.0000

Minimum pairwise N of cases: 5 Significance: * - .01 ** - .001

CASE 2:

Correlations:	IPCI	INSY	COST	KSY	SYINPC	PCISY	CONSTR	SUMCR
IPCI	1.0000	.5987	-.3250	-.2922	-.4853	-.1382	.7863	.3835
INSY	.5987	1.0000	-.6796	-.5458	-.2278	-.0694	.9539*	.7784
COST	-.3250	-.6796	1.0000	.1186	-.4163	-.4285	-.5349	-.9082
KSY	-.2922	-.5458	.1186	1.0000	-.0043	-.3164	-.5037	-.5190
SYINPC	-.4853	-.2278	-.4163	-.0043	1.0000	.8963	-.4501	.4067
PCISY	-.1382	-.0694	-.4285	-.3164	.8963	1.0000	-.2212	.5509
CONSTR	.7863	.9539*	-.5349	-.5037	-.4501	-.2212	1.0000	.6327
SUMCR	.3835	.7784	-.9082	-.5190	.4067	.5509	.6327	1.0000

Minimum pairwise N of cases: 5 Significance: * - .01 ** - .001

CASE 3:

Correlations:	IPCI	INSY	COST	KSY	SYINPC	PCISY	CONSTR	SUMCR
IPCI	1.0000	-.6423	-.9216	-.3828	-.4818	-.0308	.3204	-.3924
INSY	-.6423	1.0000	.5770	-.1313	.9233	.7641	.4576	.9266
COST	-.9216	.5770	1.0000	.1186	.5566	.0426	-.4594	.4387
KSY	-.3828	-.1313	.1186	1.0000	-.4786	-.6224	-.2804	-.4874
SYINPC	-.4818	.9233	.5566	-.4786	1.0000	.8498	.4049	.9888**
PCISY	-.0308	.7641	.0426	-.6224	.8498	1.0000	.7843	.9121
CONSTR	.3204	.4576	-.4594	-.2804	.4049	.7843	1.0000	.5367
SUMCR	-.3924	.9266	.4387	-.4874	.9888**	.9121	.5367	1.0000

Minimum pairwise N of cases: 5 Significance: * - .01 ** - .001

Case 2, in Table 10, shows the correlations obtained for primary rank pavement. Again, none of the correlations are indicated as significant. The highest correlation is -0.9082 between cost and the sum of the square yardage constructed and the square yardage whose PCI increased. The negative sign of the correlation is again opposite of what is expected, since constructing new pavement or increasing the PCI of existing pavement should increase costs, not decrease them.

There are several possible causes for the poor correlations observed in Case 1 and Case 2. The first is the fact that usually not all the pavement is inspected each fiscal year, nor are the same sections inspected from year to year. In the analysis it was assumed that nearly all improved or newly constructed pavement would be inspected, but that may not have been the case. Secondly, it was not possible to determine exactly in what fiscal year a change in PCI occurred. If a change in PCI occurred between say, 1984 and 1985, the change was assigned to 1985, however, the change could have occurred in 1984, but was not inspected until 1985. This problem is compounded when the time between inspections is greater than 1 year. For the data set analyzed, 56% of the changes in PCI occurred over 1 year, 22% occurred over 2 years, and 21% occurred over 3 or more years. One percent of the changes occurred within the same year.* Similarly, because of delays between contracting and construction, it is likely that funds shown as expended in a given fiscal year do not result in changes in pavement condition, or construction, until a later fiscal year. Because complete PAVER and Red Book data were only available for 5 years, it was not possible to fully explore this time series aspect of the data. However, the possibility of a lag effect in the relationship between the cost and pavement quality data was briefly analyzed by examining the correlation between each fiscal year's PAVER data with Red Book cost data from the previous fiscal year. These results, for primary pavement, are shown as Case 3.

Unfortunately, the results for Case 3 do not show much improvement over the previous correlations. No significant correlations are indicated between the cost and pavement quality variables. The strongest correlation of -0.9216 occurs between the inspection PCI and the cost, but again, the negative sign is counter to what would be expected. That is, we do not expect that funds expended in a previous year for maintenance or construction to result in lower PCIs the next year.

*The reason for inspections to occur over intervals of less than 1 year could not be determined from the data, however, close inspection of the data indicated that they did indeed occur.

Duration of PAVER Implementation

It is expected that the implementation of PAVER by an installation will, over the long term, affect the costs of pavement management. Evaluation of these effects will require a longer time series of data than was available for this analysis. However, it was possible to estimate the average annual cost (starting in 1980) for pavement management for all the installations prior to PAVER implementation and compare these costs with costs for years after PAVER implementation. The results are shown in Figure 28. Costs have been adjusted for inflation assuming an annual rate of 4.5%. The results shown if Figure 28 are inconclusive. The implementation year costs are somewhat higher than for the average of the years before, possibly reflecting costs associated with initial PAVER inspections. The next year following costs are sharply lower, but by the second year after implementation, costs are about the same as before. A closer examination of effects of length of time of PAVER implementation must wait until data for several more years is available.

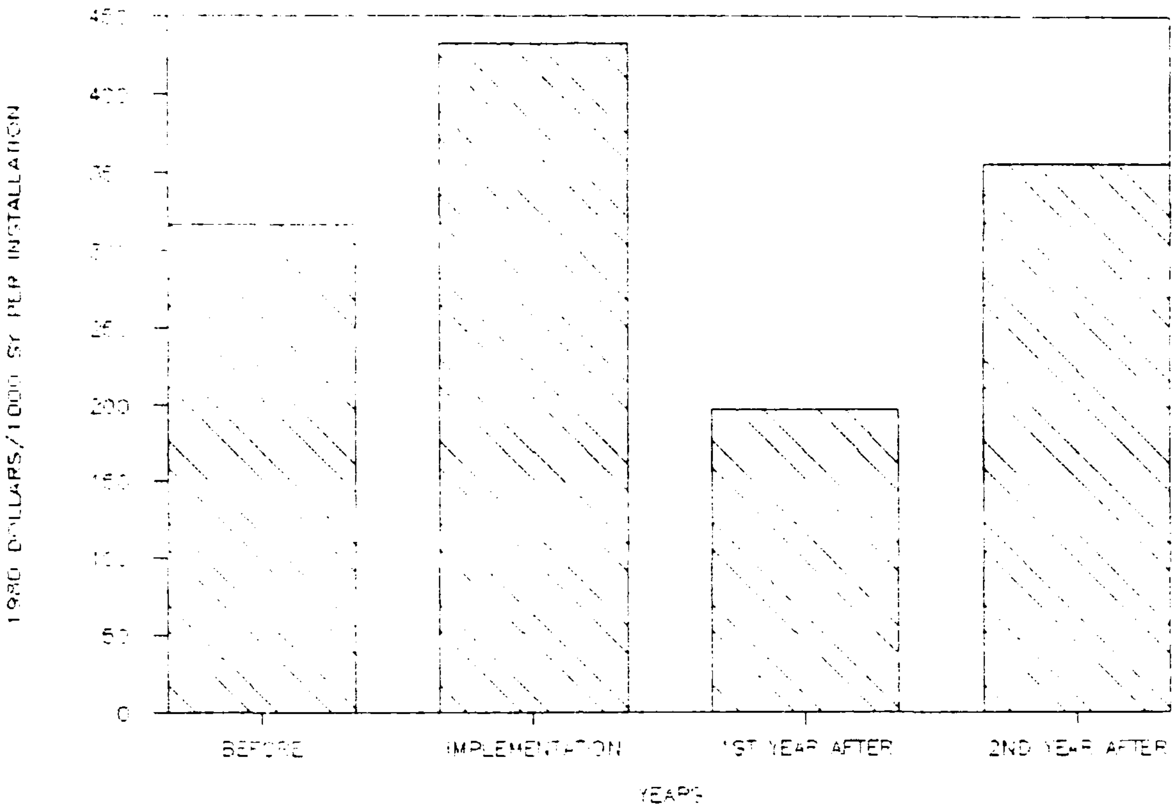

Figure 28. PAVER implementation by average annual unit costs for maintenance.

Effects of Other Variables

Up to this point, only the relationships between PAVER and Red Book data have been examined. Because of the low level of correlation observed in many cases, the effects of other variables such as weather and base population were examined. Also, data on the costs for pavement surface seal at FORSCOM installations were examined as an additional measure of the "costs of doing business," as a supplement to the AR415-17 regional cost adjustment factors used previously.

Nomenclature for the additional variables is as follows:

1. FREEZE - annual freeze-thaw cycles, estimated from 1988 data
2. TMAX - average annual maximum temperature °F
3. TMIN - average annual minimum temperature °F
4. SNOW - average annual snowfall in inches
5. SNOW87 - annual snowfall for 1987, inches
6. POPLTN - base population in 1988, from Red Book
7. SSCOST - cost for pavement surface seal at FORSCOM installations from USACERL ltr. to FORSCOM FCEN-RDF dated 28 Nov 1988

All weather data was from "NOAA Local Climatological Data - Annual Summary With Comparative Data" summaries obtained for cities located near each of the installations. Population data was obtained from the Red Book. Population data was included as a surrogate for traffic data, which was not available in the PAVER database. All data used in this analysis are listed in Appendix C.

Correlations were examined between these variables and inspection PCI, deterioration rate, average annual cost, average annual unit cost, adjusted average annual unit cost, and unit costs for 1987. The results of the correlation analysis are shown in Table 11. There are several significant correlations. The deterioration rate is found to be significantly correlated with freeze-thaw cycles. The positive sign of the correlation indicates that installations having larger numbers of freeze-thaw cycles have higher pavement deterioration rates. Also, the 1987 unit cost was found to be significantly correlated with the 1987 snowfall. This positive correlation suggests that installations experiencing high snowfall amounts tend to have higher unit costs for pavement maintenance. This affect appears to occur for current years. It should be noted that the 1987 snowfall amounts are strongly correlated with annual average snowfall, indicating that 1987 was a very typical snowfall year. For this reason, the correlation of 1987 unit cost with annual average snowfall can probably be discounted, particularly since annual average cost did not correlate significantly with average snowfall.

The average annual cost is seen to be positively correlated with installation population. However, average unit costs are not correlated with population, which may indicate that the population variable is more an indication of installation size than an indicator of traffic.

No significant relationships were observed between any of the variables and the surface seal cost variable.

Table 11. Correlations For Weather and Population Variables

Correlations:	RKSY	IPCI	DRATE	CAV	UCAV	UCADJ
RKSY	1.0000	-.1933	.0383	.6454**	-.3748	-.2717
IPCI	-.1933	1.0000	-.3167	.0428	.2931	.2904
DRATE	.0383	-.3167	1.0000	.4219*	.3801	.4565*
CAV	.6454**	.0428	.4219*	1.0000	.3127	.3991*
UCAV	-.3748	.2931	.3801	.3127	1.0000	.9051**
UCADJ	-.2717	.2904	.4565*	.3991*	.9051**	1.0000
UC87	-.3158	.4059	.0414	.2552	.6212**	.4841*
FREEZE	-.2725	-.2779	.4095*	-.0685	.1041	.0720
TMAX	.3071	-.0507	.0341	.2641	-.2365	.0831
TMIN	.3188	.0376	-.0361	.2562	-.2352	.0948
SNOW	-.3725	.0412	.0267	-.0977	.2787	.0541
SNOW87	-.3816	-.0165	.0348	-.0932	.2538	.0661
POPLTN	.6056**	.0227	.3290	.6537**	-.0643	.0436
SSCOST	-.0412	.4416	-.1627	.0692	.0729	.1487

	UC87	FREEZE	TMAX	TMIN	SNOW	SNOW87	POPLTN	SSCOST
RKSY	-.3158	-.2725	.3071	.3188	-.3725	-.3816	.6056**	-.0412
IPCI	.4059	-.2779	-.0507	.0376	.0412	-.0165	.0227	.4416
DRATE	.0414	.4095*	.0341	-.0361	.0267	.0348	.3290	-.1627
CAV	.2552	-.0685	.2641	.2562	-.0977	-.0932	.6537**	.0692
UCAV	.6212**	.1041	-.2365	-.2352	.2787	.2538	-.0643	.0729
UCADJ	.4841*	.0720	.0831	.0948	.0541	.0661	.0436	.1487
UC87	1.0000	.1716	-.2338	-.2330	.4990*	.5216*	-.0160	.2127
FREEZE	.1716	1.0000	-.3481	-.3869	.5320**	.6074**	.0520	.1112
TMAX	-.2338	-.3481	1.0000	.9586**	-.7594**	-.6247**	.1767	.0108
TMIN	-.2330	-.3869	.9586**	1.0000	-.7497**	-.6185**	.2195	-.0827
SNOW	.4990*	.5320**	-.7594**	-.7497**	1.0000	.9557**	-.1883	.2438
SNOW87	.5216*	.6074**	-.6247**	-.6185**	.9557**	1.0000	-.1943	.1925
POPLTN	-.0160	.0520	.1767	.2195	-.1883	-.1943	1.0000	.1546
SSCOST	.2127	.1112	.0108	-.0827	.2438	.1925	.1546	1.0000

Minimum pairwise N of cases: 19 Significance: * - .01 ** - .001

Differences Among MACOMs

In the course of this analysis, differences have been observed in the data for the three major commands. The two most notable differences are the consistently lower unit costs for TRADOC compared with FORSCOM, and the higher degree of correlation observed between TRADOC PAVER and Red Book data. In order to examine possible reasons for these differences, summary statistics were developed for several of the variables found to be important in assessing pavement management. These summary statistics are listed in Table 12.

The summary statistics indicate only minor differences between the major commands in terms of average pavement age, PCI, and deterioration rate. A one-way analysis of variance test performed on these variables indicated that the small differences observed are not significant. The somewhat larger differences in average annual snowfall and freeze-thaw cycles were also examined and also were not found to be significant.

In terms of distribution of pavement within the data sample, the FORSCOM pavement was 29% primary and 71% other than primary. The TRADOC pavement was 40% primary and 60% other than primary, while the AMC pavement was 19% primary and 81% other than primary. Percentages of asphaltic concrete were: FORSCOM 91%, TRADOC 78%, and AMC 83%.

None of the differences observed between the PAVER or the weather data for the commands were found to be significant, and therefore it is unlikely that these variables are the source of the differences in the overall behavior of the data for the commands. Likewise, the differences in pavement rank and type between the commands is small, and pavement type was previously found to affect average cost only, not average unit cost. In addition, where pavement type did have an effect was in increased unit costs for installations with higher amounts of Portland cement concrete. TRADOC has slightly more Portland cement concrete than FORSCOM and still has lower unit costs.

Overall, the results suggest that variations observed among the commands may be due to differences in pavement management practices.

Table 12. Summary Statistics For Major Commands

FORSCOM

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
SY	1765156	1327850	121322	4260265	37068271	21
SYPR	516452	534391	4138	1899821	10845485	21
SYOR	1248704	956093	81921	3210980	26222786	21
ACSY	1612594	1199111	120895	3971804	33864470	21
PCSY	83163	111475	0	356518	1746433	21
OTSY	69398	118133	0	338759	1457368	21
AGE	15.3	9.5	4.5	33.9	321.7	21
IPCI	75.1	7.9	63.0	90.0	1577.0	21
DRATE	4.8	4.7	1.4	19.9	100.5	21
RKSY	2454	1672	106	5706	51542	21
FREEZE	61.4	38.0	0.0	133.0	1289.0	21
SNOW	28.4	31.8	0.0	109.9	597.0	21
POPLTN	25142	19933	2008	66287	527982	21

TRADOC

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
SY	1161552	808051	52096	2670590	10453964	9
SYPR	465076	454159	27093	1371797	4185686	9
SYOR	696475	502279	25003	1481289	6268278	9
ACSY	906618	820048	45955	2292908	8159561	9
PCSY	64079	118978	0	371811	576715	9
OTSY	190854	265145	0	634981	1717688	9
AGE	12.1	3.2	8.2	17.6	109.1	9
IPCI	73.3	10.5	56.0	86.0	660.0	9
DRATE	3.6	1.1	2.1	4.8	32.1	9
RKSY	2829	1918	802	6830	25457	9
FREEZE	73.0	14.9	51.0	93.0	657.0	9
SNOW	12.2	8.4	.5	23.2	110.2	9
POPLTN	30743	19116	9480	60500	276688	9

AMC

Variable	Mean	Std Dev	Minimum	Maximum	Sum	N
SY	1061236	936997	40280	2204899	4244942	4
SYPR	205555	226086	0	487941	822218	4
SYOR	855681	715331	40280	1716958	3422724	4
ACSY	882204	881887	16386	1868422	3528817	4
PCSY	19503	29744	0	62804	78013	4
OTSY	159528	172860	0	340545	638112	4
AGE	14.8	12.8	3.2	32.4	59.0	4
IPCI	78.0	13.9	66.0	98.0	312.0	4
DRATE	3.1	1.7	1.2	5.3	12.2	4
RKSY	1237	431	756	1801	4948	4
FREEZE	56.5	33.3	24.0	90.0	226.0	4
SNOW	29.6	53.6	1.3	109.9	118.5	4
POPLTN	1616	542	998	2100	6465	4

4 DEVELOPMENT OF PAVEMENT MANAGEMENT PERFORMANCE INDICATORS

The low degree of correlation observed among some of the variables increases the difficulty of developing performance indicators. However, even the low level correlations provide some clues to possibly useful parameters. The correlation matrices indicated that the Red Book cost variables are related to the PCI at last inspection, the rate of deterioration, and the installation area. Of these variables, all but the installation area were examined as elements of a pavement management performance index. Installation area was omitted because it may be an indicator of economies of scale for the larger installations. Graphical rankings of the installations based on PCI, deterioration rate, and average unit cost are shown in Figures 29, 30, and 31.

It is understood that PCI is the ultimate indicator of pavement maintenance, that is, if an installation's pavement does not exceed some minimum PCI of, say 55, its pavement management is unsuccessful. The performance indicators developed here are intended to aid in distinguishing among installations which meet the minimum criteria.

Potential performance indicators were developed based on the data for pavement of all ranks for the combined FORSCOM, TRADOC, and AMC data. At a later date, as more TRADOC installations implement PAVER, it may be useful to develop separate TRADOC indicators due to the differences observed between the FORSCOM and TRADOC data sets.

Indicator Number One

The first potential performance indicator was developed by assuming a relationship:

$$\text{UCAV} = K_1 \times \text{DRATE} \tag{1}$$

exists. Implicit in this relationship is the assumption that the deterioration rate DRATE, is the independent variable. The equation can also be written as:

$$\text{UCAV} = K_1 \times \frac{(100 - \text{IPCI})}{\text{Age}} \tag{2}$$

This form of first order rate equation is similar to many well-known physical laws such as Fourier's law of heat transfer or Fick's law of mass diffusion. In this formulation, the deterioration rate acts as a determinant driving the expenditure of funds for maintenance. In this context the deterioration rate is seen as a measure of cumulative pavement distress mechanisms. The performance indicator is then K_1, given by:

$$K_1 = \frac{\text{UCAV}}{\text{DRATE}} \tag{3}$$

The ranking of installations based on this indicator is shown in Table 13. Unfortunately, it can be seen immediately that this indicator is not successful since review of the PCI data reveals that Ft. Chaffee, indicated here as the maintenance champion, has a PCI of 56.

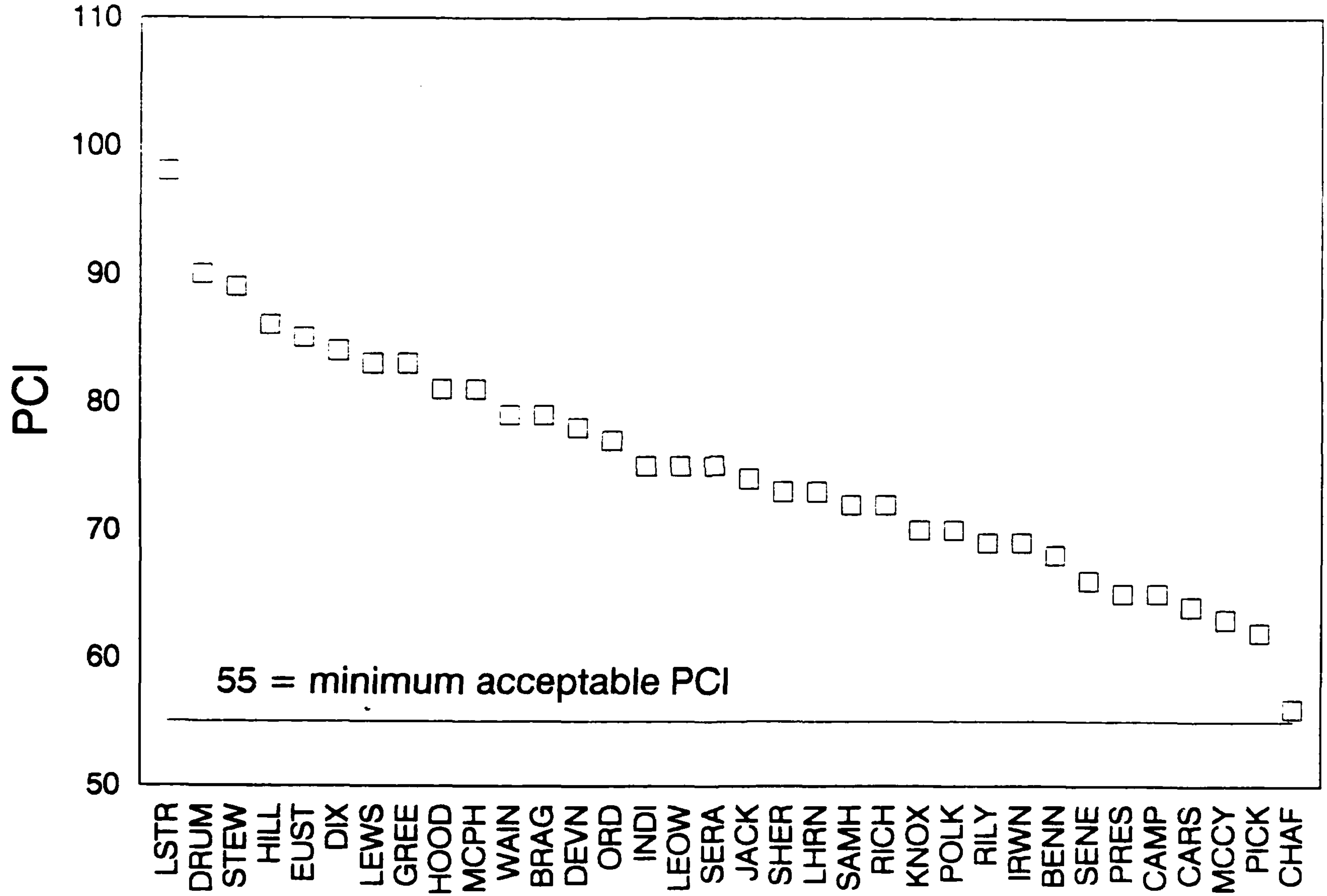

Figure 29. Installation rankings by PCI.

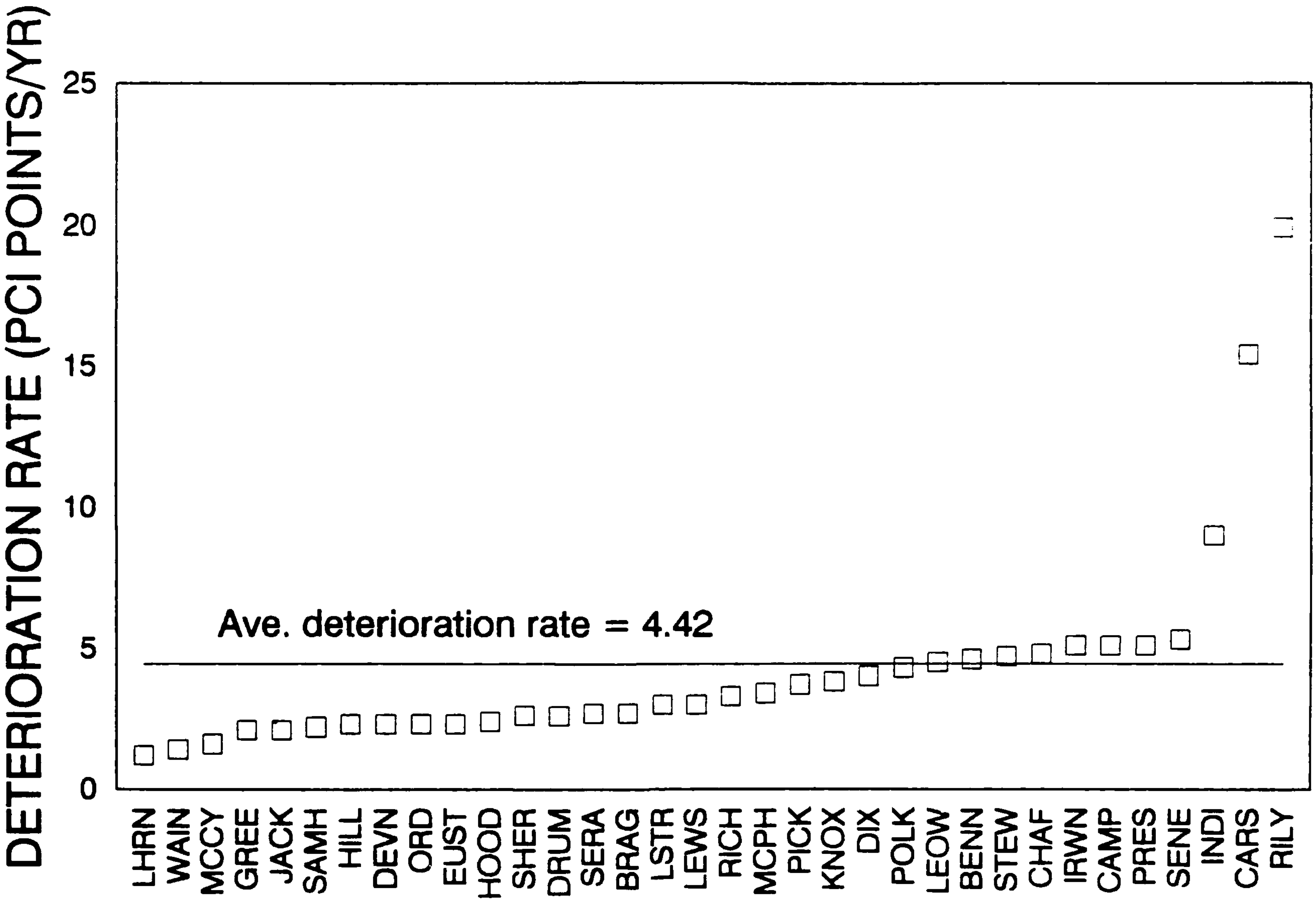

Figure 30. Installation rankings by deterioration rate.

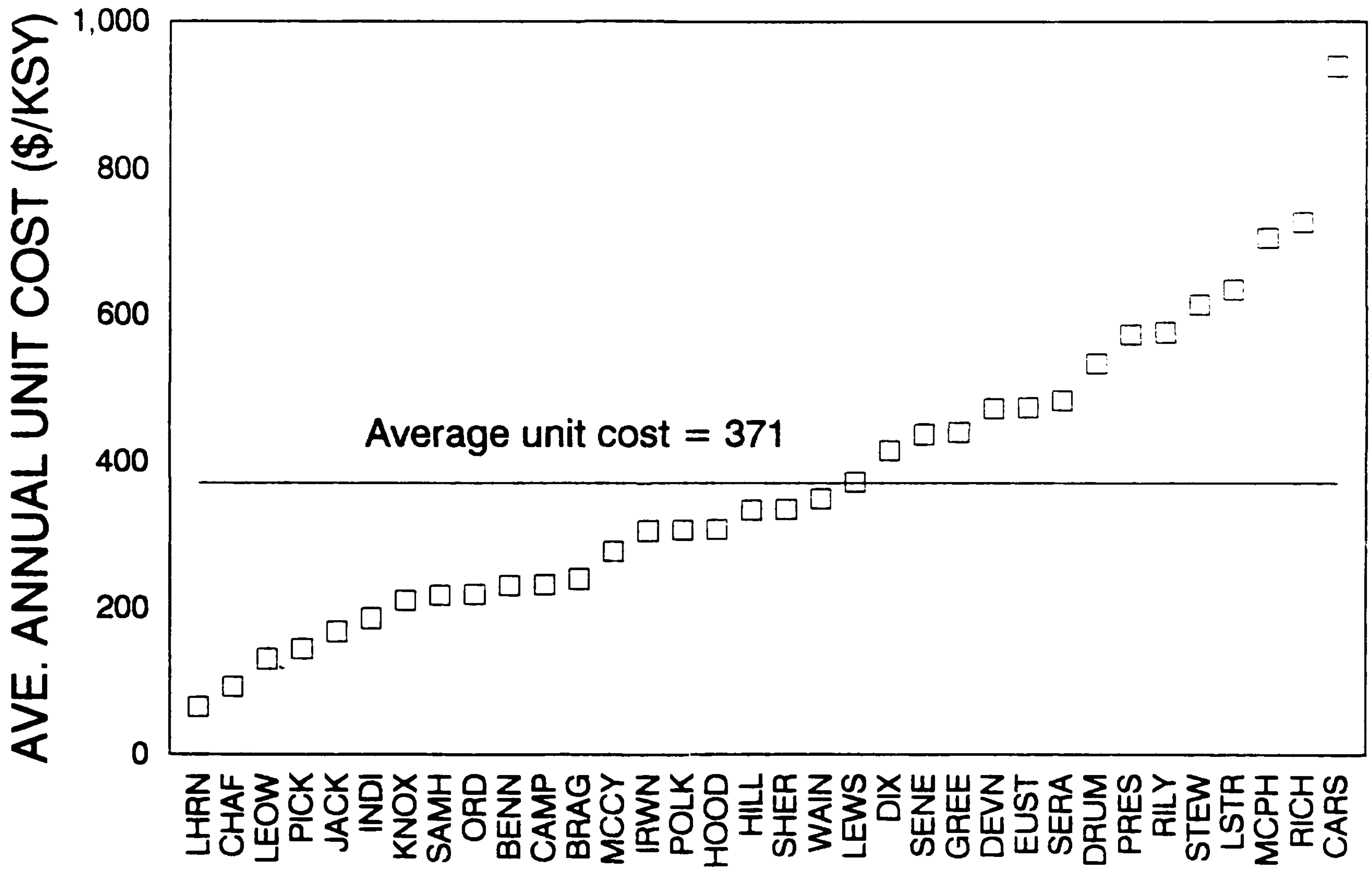

Figure 31. Installation rankings by average annual unit costs for maintenance.

Table 13. Rankings Based on Pavement Management Indicator - K_1

K_1	Inst.	MACOM	IPCI	DRATE	UCAV
19.3	CHAF	TRADOC	56	4.8	92
20.5	INDI	FORSCOM	75	9.0	185
28.6	LEOW	TRADOC	75	4.5	130
28.9	RILY	FORSCOM	69	19.9	576
39.4	PICK	TRADOC	62	3.7	144
45.6	CAMP	FORSCOM	65	5.1	231
50.1	BENN	TRADOC	68	4.6	230
54.2	LHRN	AMC	73	1.2	65
56.1	KNOX	TRADOC	70	3.8	210
60.5	IRWN	FORSCOM	69	5.1	305
61.1	CARS	FORSCOM	64	15.4	938
71.9	POLK	FORSCOM	70	4.3	306
78.2	JACK	TRADOC	74	2.1	167
82.5	SENE	AMC	66	5.3	437
87.5	BRAG	FORSCOM	79	2.7	239
95.2	ORD	FORSCOM	77	2.3	218
98.8	SAMH	FORSCOM	72	2.2	217
102.7	DIX	TRADOC	84	4.0	415
113.2	PRES	FORSCOM	65	5.1	573
122.2	LEWS	FORSCOM	83	3.0	372
127.5	HOOD	FORSCOM	81	2.4	307
128.5	SHER	FORSCOM	73	2.6	334
132.0	STEW	FORSCOM	89	4.7	614
147.9	HILL	TRADOC	86	2.3	333
169.9	MCCY	FORSCOM	63	1.6	277
178.9	SERA	AMC	75	2.7	483
202.0	EUST	TRADOC	85	2.3	473
204.4	DRUM	FORSCOM	90	2.6	533
206.3	DEVN	FORSCOM	78	2.3	472
206.5	MCPH	FORSCOM	81	3.4	705
208.0	GREE	FORSCOM	83	2.1	440
211.3	LSTR	AMC	98	3.0	634
221.6	RICH	FORSCOM	72	3.3	726
243.4	WAIN	FORSCOM	79	1.4	349

Indicator Number Two

The failure of the first performance indicator showed the necessity of including PCI as an element in the indicator. Also, since assuming a form of physical law did not result in success, the development of the second indicator proceeded in an empirical fashion. The following observation can be made about the "best" managed pavement and the "worst" managed pavement:

"Best"	"Worst"
IPCI - high	IPCI - low
DRATE - low	DRATE - high
UCAV - low	UCAV - high.

Based on these criteria a performance indicator K_2 was constructed as being:

$$K_2 = \frac{UCAV \times DRATE}{(IPCI - 55)} \quad . \tag{4}$$

Rankings based on this indicator are shown in Table 14. This indicator is attractive because it is easy to understand conceptually and, since it is constructed without relying on physical laws, weighting factors can be inserted such as:

$$K_2 = \frac{(W_1 \times UCAV) \times (W_2 \times DRATE)}{W_3 \times (IPCI - 55)} \tag{5}$$

to reflect command emphasis on different facets of pavement management.

Indicator Number Three

Out of reluctance to discard physical reasoning completely, indicator number three was constructed by modifying indicator number one as follows:

$$K_3 = \frac{UCAV}{DRATE} \times \frac{1}{(IPCI - 55)} \, . \tag{6}$$

Rankings based on this indicator are shown in Table 15.

Table 14. Rankings Based on Pavement Management Indicator - K_2

K_2	Inst.	MACOM	IPCI	DRATE	UCAV
4.3	LHRN	AMC	73	1.2	65
19.0	JACK	TRADOC	74	2.1	167
21.0	WAIN	FORSCOM	79	1.4	349
22.9	ORD	FORSCOM	77	2.3	218
24.4	HILL	TRADOC	86	2.3	333
27.8	BRAG	FORSCOM	79	2.7	239
28.2	SAMH	FORSCOM	72	2.2	217
28.6	HOOD	FORSCOM	81	2.4	307
29.2	LEOW	TRADOC	75	4.5	130
33.1	GREE	FORSCOM	83	2.1	440
36.8	EUST	TRADOC	85	2.3	473
40.1	DRUM	FORSCOM	90	2.6	533
40.1	LEWS	FORSCOM	83	3.0	372
44.2	LSTR	AMC	98	3.0	634
47.5	DEVN	FORSCOM	78	2.3	472
48.1	SHER	FORSCOM	73	2.6	334
51.8	KNOX	TRADOC	70	3.8	210
58.1	MCCY	FORSCOM	63	1.6	277
58.7	DIX	TRADOC	84	4.0	415
65.2	SERA	AMC	75	2.7	483
78.5	PICK	TRADOC	62	3.7	144
82.3	INDI	FORSCOM	75	9.0	185
83.0	BENN	TRADOC	68	4.6	230
85.2	STEW	FORSCOM	89	4.7	614
86.1	POLK	FORSCOM	70	4.3	306
93.6	MCPH	FORSCOM	81	3.4	705
112.5	IRWN	FORSCOM	69	5.1	305
122.0	CAMP	FORSCOM	65	5.1	231
141.7	RICH	FORSCOM	72	3.3	726
210.6	SENE	AMC	66	5.3	437
302.7	PRES	FORSCOM	65	5.1	573
636.1	CHAF	TRADOC	56	4.8	92
821.9	RILY	FORSCOM	69	19.9	576
1633.0	CARS	FORSCOM	64	15.4	938

Table 15. Rankings Based on Pavement Management Indicator - K_3

K_3	Inst.	MACOM	IPCI	DRATE	UCAV
1.0	INDI	FORSCOM	75	9.0	185
1.4	LEOW	TRADOC	75	4.5	130
2.1	RILY	FORSCOM	69	19.9	576
3.0	LHRN	AMC	73	1.2	65
3.6	DIX	TRADOC	84	4.0	415
3.7	KNOX	TRADOC	70	3.8	210
3.7	BRAG	FORSCOM	79	2.7	239
3.9	BENN	TRADOC	68	4.6	230
3.9	STEW	FORSCOM	89	4.7	614
4.2	JACK	TRADOC	74	2.1	167
4.3	LEWS	FORSCOM	83	3.0	372
4.4	ORD	FORSCOM	77	2.3	218
4.4	IRWN	FORSCOM	69	5.1	305
4.7	POLK	FORSCOM	70	4.3	306
4.8	CAMP	FORSCOM	65	5.1	231
4.8	HILL	TRADOC	86	2.3	333
4.9	LSTR	AMC	98	3.0	634
4.9	HOOD	FORSCOM	81	2.4	307
5.8	SAMH	FORSCOM	72	2.2	217
5.9	PICK	TRADOC	62	3.7	144
5.9	DRUM	FORSCOM	90	2.6	533
6.7	EUST	TRADOC	85	2.3	473
6.9	CARS	FORSCOM	64	15.4	938
7.1	SHER	FORSCOM	73	2.6	334
7.4	GREE	FORSCOM	83	2.1	440
7.5	SENE	AMC	66	5.3	437
8.0	MCPH	FORSCOM	81	3.4	705
8.9	SERA	AMC	75	2.7	483
9.1	DEVN	FORSCOM	78	2.3	472
10.2	WAIN	FORSCOM	79	1.4	349
11.8	PRES	FORSCOM	65	5.1	573
13.2	RICH	FORSCOM	72	3.3	726
21.8	MCCY	FORSCOM	63	1.6	277
27.7	CHAF	TRADOC	56	4.8	92

5 CONCLUSIONS

The data analysis which has been performed supports several conclusions regarding PAVER and Red Book pavement maintenance data. These conclusions are as follows:

1. Analysis of the Red Book data alone indicates that the cost of pavement maintenance per 1000 square yards has been consistently lower for TRADOC installations than for FORSCOM installations for 1984 through 1987, the last 4 years for which data was available. No significant differences were observed in overall PCI between the commands.

2. Analysis of PAVER and Red Book data for FORSCOM installations showed only a marginal correlation between Red Book cost data and PAVER PCI data. This may indicate that expenditures for pavement maintenance do not necessarily lead to higher PCIs. It is more likely,however, that this indicates that present maintenance practices run from good to bad. Similar tasks may be performed more or less effectively at each installation, resulting in varying costs to acquire equivalent PCIs. Poor correlations would be expected under these circumstances.

3. Analysis of PAVER and Red Book data for TRADOC installations indicated a strong degree of correlation between PAVER PCI data and Red Book cost data. This may be an indication of the effectiveness of the TRADOC pavement management program. As more TRADOC installations implement PAVER it will be possible to further evaluate the correlations observed.

4. It was demonstrated that even without significant correlations between PAVER and Red Book data, it is possible to develop a rational pavement management performance indicator by ranking installations based on favorable or unfavorable pavement quality and maintenance cost characteristics. As stated previously, the objective of this work effort was to develop an analytical method of using available Red Book and PAVER PCI data to measure DEH performance in managing pavement maintenance. While the small amount of data, and the low degree of correlation observed, did not allow conclusive determination of a pavement management performance indicator, the analysis did indicate several potentially useful parameters. These parameters, namely IPCI; the inspection year PCI, DRATE; the deterioration rate, and UCAV; the average annual unit cost, were shown to be useful in construction of prototype performance indicators, of which K_2 was judged to be the most appropriate.

In spite of the poor correlations, the concept of using the PAVER inspection methodology and Red Book (or other) cost data to develop management performance indicators is sound. PAVER's ability to objectively evaluate pavement condition is a powerful tool which can be used to manage pavement maintenance and, with cost data, also can be used to evaluate the effectiveness of management programs.

APPENDIX A

DATA MATRICES FOR ALL RANK AND PRIMARY RANK PAVEMENT

PCI AND RED BOOK DATA - PAVEMENT OF ALL RANKS
(-1 indicates missing data)

	SY	ACSY	PCSY	YEAR	AGE	IPCI	PCI89	DRATE	PKSY	CAV	UCAV	UCADJ	KS87	UC87
BRAG	3581161	3370118	155388	1986.1	11.5	79	70	2.7	5706	1314146	239	200	6604	95
CAMP	3455341	3098826	356518	1986.3	24.4	65	53	5.1	3477	812803	231	207	3591	190
CARS	1503591	1279708	8226	1987.0	6.4	64	49	15.4	1534	1466033	938	788	1554	665
DEVN	894907	894907	0	1987.0	9.1	78	73	2.3	1521	690056	472	340	1853	229
DRUM	528698	446508	82190	1987.0	8.1	90	84	2.6	1501	1310918	533	399	2695	2114
HOOD	4260265	3971804	43086	1986.7	10.3	81	76	2.4	5468	1698749	307	280	4392	[illegible]
SAMH	1394245	1375167	19078	1987.0	12.7	72	69	2.2	2367	476789	217	208	2821	51
INDI	555566	546621	0	1986.0	9.4	75	64	9.0	1278	[illegible]	185	151	[illegible]	[illegible]
LEWS	3212982	2757068	117369	1988.0	6.9	83	80	3.0	2410	694756	372	303	3114	[illegible]
MCCY	771186	703975	67211	1986.0	33.9	63	58	1.6	1077	393212	277	230	1226	143
MCPH	121322	120895	427	1987.0	8.7	81	75	3.4	883	391105	705	686	-1	-1
ORD	3013773	2930470	21719	1985.7	11.9	77	70	2.3	4939	322614	218	163	6972	119
POLK	2324209	2127451	196758	1988.0	18.6	70	66	4.3	4903	1461061	306	243	4533	235
PRES	3451776	3098826	352950	1986.3	24.4	65	53	5.1	2414	837941	573	408	1490	246
RILY	2516052	2111383	211826	1986.0	8.3	69	50	19.9	3017	1542729	576	512	1	-1
SHER	212341	212341	0	1987.0	10.2	73	68	2.6	685	227861	334	285	[illegible]	[illegible]
STEW	925351	897549	27802	1986.0	4.5	89	77	4.7	2485	1088540	614	574	1640	1116
GREE	2556364	2142185	75420	1988.0	32.1	83	91	2.1	106	16953	440	167	102	[illegible]
RICH	665970	665970	0	1987.0	29.2	72	66	3.3	739	531764	726	316	631	1317
WAIN	478379	468581	9798	1987.0	30.3	79	76	1.4	3691	480080	349	110	4254	171
IRWN	644784	644117	667	1986.0	10.8	69	54	5.1	1341	403104	305	215	1541	[illegible]
BENN	2670590	2292908	371811	1988.0	13.1	68	63	4.6	6830	1545270	230	231	7723	32
CHAF	954530	329530	32430	1986.8	14.9	56	46	4.8	4357	375733	92	94	6133	47
DIX	52096	45955	6141	1987.0	8.4	84	75	4.0	1517	629225	415	325	1497	237
EUST	458477	383682	74795	1980.1	10.0	85	66	2.3	802	393572	473	384	806	212
HILL	898746	263765	0	1987.0	17.6	86	81	2.3	1389	303946	333	296	-1	-1
JACK	1122461	783860	0	1986.5	14.5	74	68	2.1	2129	353419	167	139	2114	117
KNOX	1940561	1871308	69253	1984.0	10.3	70	52	3.8	3368	658394	210	169	4237	113
PICK	678099	510576	21858	1987.5	12.1	62	57	3.7	1478	176372	144	127	-1	1
LEOW	1678404	1677977	427	1986.0	8.2	75	62	4.5	3597	476864	130	97	-1	-1
SERA	2204899	1868422	62804	1985.5	15.4	75	66	2.7	1801	866683	483	340	1621	1192
SENE	1371395	1371395	0	1988.0	8.0	66	61	5.3	1242	544691	437	351	1336	493
LHRN	628368	272614	15209	1985.0	32.4	73	68	1.2	756	49219	65	58	784	73
LSTR	40280	16386	0	1985.0	3.2	98	86	3.0	1149	675863	634	576	1652	[illegible]

PCI AND RED BOOK DATA - PRIMARY PAVEMENTS
(-1 indicates missing data)

	SY	ACSY	PCSY	YEAR	AGE	IPCI	PCI89	DRATE	RKSY	CAV	UCAV	UCADJ	KS87	UC87
BRAG	824565	809836	14729	1986.0	10.3	77	69	2.7	5706	1314146	239	200	6604	95
CAMP	1536166	1488246	47920	1986.2	18.6	64	49	6.8	3477	812803	231	207	3581	100
CARS	572505	570508	1997	1987.1	6.3	66	52	7.0	1534	1466033	938	788	1554	665
DEVN	114648	114648	0	1987.0	7.7	83	80	1.9	1521	690056	472	340	1853	220
DRUM	4138	4138	0	1987.0	2.6	98	96	0.8	1501	1310918	533	399	2685	2114
HOOD	1899821	1879691	20130	1986.8	9.5	81	76	2.2	5468	1698749	307	280	4392	380
SAMH	168805	168805	0	1987.0	9.0	79	75	2.3	2367	476789	217	208	2824	51
INDI	91214	91214	0	1986.0	10.5	81	74	2.3	1278	258913	185	151	1770	203
LEW2	676377	667245	9132	1988.0	6.6	85	82	2.6	2410	694756	372	303	3114	279
MCCY	299522	287472	12050	1986.0	34.7	61	56	1.6	1077	303212	277	230	1226	143
MCPH	39401	39401	0	1987.0	4.4	88	78	6.2	883	391105	705	686	-1	-1
ORD	729133	729133	0	1986.3	9.5	77	69	3.2	4939	922614	218	163	6972	118
POLK	938353	851616	86737	1988.0	21.5	70	65	5.5	4903	1461061	306	243	4533	235
FRES	240796	-1	-1	1987.9	17.8	72	70	2.0	2414	837941	573	408	1490	246
RILY	1351220	1236104	75646	1986.0	5.2	74	54	22.1	3017	1542729	576	512	-1	-1
SHER	7861	7861	0	1987.0	5.1	88	85	1.8	685	227861	334	285	885	332
STEW	177364	177364	0	1986.0	5.4	84	64	7.9	2485	1088540	614	574	1640	1116
GREE	505289	505289	0	1988.0	16.0	85	82	2.3	106	46953	440	167	102	663
RICH	235634	235634	0	1987.0	27.7	70	65	2.5	739	531764	726	316	681	1347
WAIN	165132	165132	0	1987.0	31.7	81	78	1.5	3691	480080	349	110	4254	171
IRWN	267541	267541	0	1986.0	3.8	77	59	6.0	1341	403104	305	215	1541	0
BENN	1371797	1178383	193414	1988.0	10.9	68	63	4.9	6830	1545270	230	234	7723	92
CHAF	523645	245298	0	1986.9	11.7	51	41	6.0	4357	375733	92	94	6133	47
DIX	27093	27093	0	1987.0	4.2	83	73	5.1	1517	629225	415	325	1497	237
EUST	138350	117943	20407	1981.0	7.7	90	72	2.3	802	393572	473	384	806	213
HILL	637841	213928	0	1987.0	18.5	87	83	1.9	1389	303946	333	296	-1	-1
JACK	160692	160692	0	1986.2	7.8	86	79	2.4	2129	353419	167	138	2114	117
KNOX	959438	923251	36187	1984.0	8.9	73	53	4.2	3368	658394	210	169	4287	113
PICK	169715	169715	0	1987.9	8.8	60	54	5.1	1478	176372	144	127	-1	-1
LEOW	197115	197115	0	1986.0	7.0	75	62	4.3	3587	476864	130	97	-1	-1
SERA	487941	487941	0	1986.5	8.6	77	68	3.6	1801	866683	483	340	1621	1192
SENE	286298	286298	0	1988.0	5.9	73	68	4.8	1242	544691	437	351	1336	433
LHRN	47979	34868	0	1985.0	13.5	93	85	2.0	756	49219	65	58	784	73

APPENDIX B

CORRELATION MATRICES FOR DATA PARTITIONED BY MACOM

Correlation Matrix for All Pavements - FORSCOM Only

Correlations:	SY	ACSY	PCSY	AGE	IPCI	PCI89
SY	1.0000	.9967**	.6412**	.0371	-.0824	-.0945
ACSY	.9967**	1.0000	.6144*	.0269	-.0766	-.0839
PCSY	.6412**	.6144*	1.0000	.2530	-.3600	-.3925
AGE	.0371	.0269	.2530	1.0000	-.3461	-.1015
IPCI	-.0824	-.0766	-.3600	-.3461	1.0000	.9152**
PCI89	-.0945	-.0839	-.3925	-.1015	.9152**	1.0000
DRATE	.0572	.0194	.1968	-.3336	-.3870	-.6438**
RKSY	.6746**	.7108**	.3458	-.1279	.0477	.0274
CAV	.5024	.5065*	.3223	-.4189	.0525	-.1230
UCAV	-.2518	-.2841	-.1050	-.1409	.0162	-.1297
UCADJ	-.1810	-.2071	-.0475	-.4644	.0077	-.1967
KS87	.5320*	.5730*	.1860	-.2014	.1651	.1729
UC87	-.3108	-.3285	-.1627	-.1037	.5047	.4022

Minimum pairwise N of cases: 19 Significance: * - .01 ** - .001

Correlations:	DRATE	RKSY	CAV	UCAV	UCADJ	KS87
SY	.0572	.6746**	.5024	-.2518	-.1810	.5320*
ACSY	.0194	.7108**	.5065*	-.2841	-.2071	.5730*
PCSY	.1968	.3458	.3223	-.1050	-.0475	.1860
AGE	-.3336	-.1279	-.4189	-.1409	-.4644	-.2014
IPCI	-.3870	.0477	.0525	.0162	.0077	.1651
PCI89	-.6438**	.0274	-.1230	-.1297	-.1967	.1729
DRATE	1.0000	-.0500	.4136	.4347	.5298*	-.2242
RKSY	-.0500	1.0000	.6645**	-.4100	-.2596	.9232**
CAV	.4136	.6645**	1.0000	.2232	.3719	.5334*
UCAV	.4347	-.4100	.2232	1.0000	.8685**	-.4755
UCADJ	.5298*	-.2596	.3719	.8685**	1.0000	-.3275
KS87	-.2242	.9232**	.5334*	-.4755	-.3275	1.0000
UC87	.0376	-.3312	.2420	.6026*	.4573	-.3036

Minimum pairwise N of cases: 19 Significance: * - .01 ** - .001

Correlations:	UC87
SY	-.3108
ACSY	-.3285
PCSY	-.1627
AGE	-.1037
IPCI	.5047
PCI89	.4022
DRATE	.0376
RKSY	-.3312
CAV	.2420
UCAV	.6026*
UCADJ	.4573
KS87	-.3036
UC87	1.0000

Minimum pairwise N of cases: 19 Significance: * - .01 ** - .001

Correlation Matrix for All Pavements - TRADOC Only

Correlations:	SY	ACSY	PCSY	AGE	IPCI	PCI89
SY	1.0000	.9525**	.7002	.0753	-.3552	-.3270
ACSY	.9525**	1.0000	.6544	-.2161	-.2662	-.3260
PCSY	.7002	.6544	1.0000	.0473	-.2086	-.1292
AGE	.0753	-.2161	.0473	1.0000	-.1757	.1308
IPCI	-.3552	-.2662	-.2086	-.1757	1.0000	.8661*
PCI89	-.3270	-.3260	-.1292	.1308	.8661*	1.0000
DRATE	.3926	.4145	.3467	-.3312	-.6124	-.5820
RKSY	.8447*	.7555*	.7592*	.0790	-.5549	-.4538
CAV	.7116	.7060	.9223**	-.1155	-.0814	-.0237
UCAV	-.4603	-.3734	.0282	-.2177	.8315*	.6552
UCADJ	-.3759	-.3281	.1558	-.1014	.7875*	.6589
KS87	.7924	.6575	.6973	.5502	-.8253	-.6089
UC87	-.6551	-.4666	-.2864	-.8505	.9599*	.7916

Minimum pairwise N of cases: 6 Significance: * - .01 ** - .001

Correlations:	DRATE	RKSY	CAV	UCAV	UCADJ	KS87
SY	.3926	.8447*	.7116	-.4603	-.3759	.7924
ACSY	.4145	.7555*	.7060	-.3734	-.3281	.6575
PCSY	.3467	.7592*	.9223**	.0282	.1558	.6973
AGE	-.3312	.0790	-.1155	-.2177	-.1014	.5502
IPCI	-.6124	-.5549	-.0814	.8315*	.7875*	-.8253
PCI89	-.5820	-.4538	-.0237	.6552	.6589	-.6089
DRATE	1.0000	.7049	.4508	-.4786	-.4592	.7774
RKSY	.7049	1.0000	.7946*	-.4976	-.3988	.9816**
CAV	.4508	.7946*	1.0000	.0590	.1554	.6688
UCAV	-.4786	-.4976	.0590	1.0000	.9849**	-.6704
UCADJ	-.4592	-.3988	.1554	.9849**	1.0000	-.5520
KS87	.7774	.9816**	.6688	-.6704	-.5520	1.0000
UC87	-.4437	-.7439	-.1888	.9442*	.8867*	-.8120

Minimum pairwise N of cases: 6 Significance: * - .01 ** - .001

Correlations:	UC87
SY	-.6551
ACSY	-.4666
PCSY	-.2864
AGE	-.8505
IPCI	.9599*
PCI89	.7916
DRATE	-.4437
RKSY	-.7439
CAV	-.1888
UCAV	.9442*
UCADJ	.8867*
KS87	-.8120
UC87	1.0000

Minimum pairwise N of cases: 6 Significance: * - .01 ** - .001

Correlation Matrix for All Pavements - AMC Only

Correlations:	SY	ACSY	PCSY	AGE	IPCI	PCI89
SY	1.0000	.9792	.7803	.0779	-.6512	-.7450
ACSY	.9792	1.0000	.6693	-.1011	-.6290	-.7272
PCSY	.7803	.6693	1.0000	.2709	-.2135	-.3095
AGE	.0779	-.1011	.2709	1.0000	-.4509	-.3870
IPCI	-.6512	-.6290	-.2135	-.4509	1.0000	.9910*
PCI89	-.7450	-.7272	-.3095	-.3870	.9910*	1.0000
DRATE	.2414	.4298	-.3315	-.7305	-.2509	-.2878
RKSY	.7797	.8139	.7308	-.4317	-.0617	-.1948
CAV	.4571	.5476	.4336	-.7499	.2843	.1586
UCAV	.0184	.1589	-.0117	-.9502	.5627	.4737
UCADJ	-.1936	-.0482	-.1905	-.9552	.6789	.6123
KS87	.2143	.3233	.2382	-.8558	.4912	.3806
UC87	.6933	.7174	.7408	-.4450	.0834	-.0507

Minimum pairwise N of cases: 4 Significance: * - .01 ** - .001

Correlations:	DRATE	RKSY	CAV	UCAV	UCADJ	KS87
SY	.2414	.7797	.4571	.0184	-.1936	.2143
ACSY	.4298	.8139	.5476	.1589	-.0482	.3233
PCSY	-.3315	.7308	.4336	-.0117	-.1905	.2382
AGE	-.7305	-.4317	-.7499	-.9502	-.9552	-.8558
IPCI	-.2509	-.0617	.2843	.5627	.6789	.4912
PCI89	-.2878	-.1948	.1586	.4737	.6123	.3806
DRATE	1.0000	.3233	.4492	.5393	.4958	.4431
RKSY	.3233	1.0000	.9044	.6003	.4190	.7663
CAV	.4492	.9044	1.0000	.8832	.7662	.9665
UCAV	.5393	.6003	.8832	1.0000	.9771	.9684
UCADJ	.4958	.4190	.7662	.9771	1.0000	.9012
KS87	.4431	.7663	.9665	.9684	.9012	1.0000
UC87	.2252	.9873*	.9252	.6448	.4781	.8115

Minimum pairwise N of cases: 4 Significance: * - .01 ** - .001

Correlations:	UC87
SY	.6933
ACSY	.7174
PCSY	.7408
AGE	-.4450
IPCI	.0834
PCI89	-.0507
DRATE	.2252
RKSY	.9873*
CAV	.9252
UCAV	.6448
UCADJ	.4781
KS87	.8115
UC87	1.0000

Minimum pairwise N of cases: 4 Significance: * - .01 ** - .001

Correlation Matrix for Primary Pavement - FORSCOM Only

Correlations:	SY	ACSY	PCSY	AGE	IPCI	PCI89
SY	1.0000	.9989**	.6566**	.0109	-.3765	-.4195
ACSY	.9989**	1.0000	.6221*	.0232	-.3949	-.4116
PCSY	.6566**	.6221*	1.0000	.1438	-.4270	-.4496
AGE	.0109	.0232	.1438	1.0000	-.5733*	-.2579
IPCI	-.3765	-.3949	-.4270	-.5733*	1.0000	.8775**
PCI89	-.4195	-.4116	-.4496	-.2579	.8775**	1.0000
DRATE	.4056	.3668	.6147*	-.2741	-.2291	-.5566*
RKSY	.6647**	.6694**	.4647	.0539	-.1904	-.1760
CAV	.6157*	.6132*	.5280*	-.2577	-.1235	-.2347
UCAV	-.2094	-.1979	-.1231	-.1605	.0079	-.1112
UCADJ	-.0889	-.0842	-.0015	-.4275	.0363	-.1853
KS87	.5120	.5003	.3476	-.0384	-.0287	-.0206
UC87	-.2684	-.2795	-.2281	-.1572	.4249	.3444

Minimum pairwise N of cases: 18 Significance: * - .01 ** - .001

Correlations:	DRATE	RKSY	CAV	UCAV	UCADJ	KS87
SY	.4056	.6647**	.6157*	-.2094	-.0889	.5120
ACSY	.3668	.6694**	.6132*	-.1979	-.0842	.5003
PCSY	.6147*	.4647	.5280*	-.1231	-.0015	.3476
AGE	-.2741	.0539	-.2577	-.1605	-.4275	-.0384
IPCI	-.2291	-.1904	-.1235	.0079	.0363	-.0287
PCI89	-.5566*	-.1760	-.2347	-.1112	-.1853	-.0206
DRATE	1.0000	.0958	.4064	.3029	.4490	.0026
RKSY	.0958	1.0000	.6645**	-.4100	-.2596	.9232**
CAV	.4064	.6645**	1.0000	.2232	.3719	.5334*
UCAV	.3029	-.4100	.2232	1.0000	.8685**	-.4755
UCADJ	.4490	-.2596	.3719	.8685**	1.0000	-.3275
KS87	.0026	.9232**	.5334*	-.4755	-.3275	1.0000
UC87	-.0606	-.3312	.2420	.6026*	.4573	-.3036

Minimum pairwise N of cases: 18 Significance: * - .01 ** - .001

Correlations:	UC87
SY	-.2684
ACSY	-.2795
PCSY	-.2281
AGE	-.1572
IPCI	.4249
PCI89	.3444
DRATE	-.0606
RKSY	-.3312
CAV	.2420
UCAV	.6026*
UCADJ	.4573
KS87	-.3036
UC87	1.0000

Minimum pairwise N of cases: 18 Significance: * - .01 ** - .001

Correlation Matrix for Primary Pavement - TRADOC Only

Correlations:	SY	ACSY	PCSY	AGE	IPCI	PCI89
SY	1.0000	.9405**	.8096*	.4768	-.2903	-.2433
ACSY	.9405**	1.0000	.8523*	.1795	-.2693	-.2931
PCSY	.8096*	.8523*	1.0000	.1042	-.1582	-.0780
AGE	.4768	.1795	.1042	1.0000	-.0727	.1142
IPCI	-.2903	-.2693	-.1582	-.0727	1.0000	.9111**
PCI89	-.2433	-.2931	-.0780	.1142	.9111**	1.0000
DRATE	.1547	.2189	.1895	-.3167	-.8393*	-.8032*
RKSY	.7722*	.7803*	.7728*	.1058	-.5472	-.4735
CAV	.7554*	.8191*	.9469**	-.0484	-.0987	-.0554
UCAV	-.1837	-.1990	.0117	-.0850	.7287	.6192
UCADJ	-.0540	-.1006	.1370	.0341	.6796	.6134
KS87	.8713	.7582	.6927	.8271	-.8350	-.6743
UC87	-.6123	-.4936	-.2842	-.8998*	.8031	.6850

Minimum pairwise N of cases: 6 Significance: * - .01 ** - .001

Correlations:	DRATE	RKSY	CAV	UCAV	UCADJ	KS87
SY	.1547	.7722*	.7554*	-.1837	-.0540	.8713
ACSY	.2189	.7803*	.8191*	-.1990	-.1006	.7582
PCSY	.1895	.7728*	.9469**	.0117	.1370	.6927
AGE	-.3167	.1058	-.0484	-.0850	.0341	.8271
IPCI	-.8393*	-.5472	-.0987	.7287	.6796	-.8350
PCI89	-.8032*	-.4735	-.0554	.6192	.6134	-.6743
DRATE	1.0000	.5177	.2785	-.4669	-.4608	.6519
RKSY	.5177	1.0000	.7946*	-.4976	-.3988	.9816**
CAV	.2785	.7946*	1.0000	.0590	.1554	.6688
UCAV	-.4669	-.4976	.0590	1.0000	.9849**	-.6704
UCADJ	-.4608	-.3988	.1554	.9849**	1.0000	-.5520
KS87	.6519	.9816**	.6688	-.6704	-.5520	1.0000
UC87	-.3835	-.7439	-.1888	.9442*	.8867*	-.8120

Minimum pairwise N of cases: 6 Significance: * - .01 ** - .001

Correlations:	UC87
SY	-.6123
ACSY	-.4936
PCSY	-.2842
AGE	-.8998*
IPCI	.8031
PCI89	.6850
DRATE	-.3835
RKSY	-.7439
CAV	-.1888
UCAV	.9442*
UCADJ	.8867*
KS87	-.8120
UC87	1.0000

Minimum pairwise N of cases: 6 Significance: * - .01 ** - .001

Correlation Matrix for Primary Pavement - AMC Only
(. - indicates coefficient could not be calculated)

Correlations:	SY	ACSY	PCSY	AGE	IPCI	PCI89
SY	1.0000	.9999*	.	-.6723	-.7865	-.8891
ACSY	.9999*	1.0000	.	-.6835	-.7959	-.8959
PCSY	.	.	1.0000	.	.	.
AGE	-.6723	-.6835	.	1.0000	.9859	.9366
IPCI	-.7865	-.7959	.	.9859	1.0000	.9820
PCI89	-.8891	-.8959	.	.9366	.9820	1.0000
DRATE	.6084	.6204	.	-.9965	-.9686	-.9042
RKSY	.9961	.9946	.	-.6043	-.7289	-.8452
CAV	.9973	.9983	.	-.7251	-.8299	-.9204
UCAV	.9305	.9360	.	-.8967	-.9581	-.9950
UCADJ	.8734	.8807	.	-.9477	-.9877	-.9995
KS87	.9910	.9930	.	-.7652	-.8620	-.9423
UC87	.9818	.9788	.	-.5195	-.6549	-.7859

Minimum pai-wise N of cases: 3 Significance: * - 01 ** - .001

Correlations:	DRATE	RKSY	CAV	UCAV	UCADJ	KS87
SY	.6084	.9961	.9973	.9305	.8734	.9910
ACSY	.6204	.9946	.9983	.9360	.8807	.9930
PCSY	.	.	.	.	.	.
AGE	-.9965	-.6043	-.7251	-.8967	-.9477	-.7652
IPCI	-.9686	-.7289	-.8299	-.9581	-.9877	-.8620
PCI89	-.9042	-.8452	-.9204	-.9950	-.9995	-.9423
DRATE	1.0000	.5359	.6652	.8568	.9178	.7090
RKSY	.5359	1.0000	.9869	.8945	.8270	.9754
CAV	.6652	.9869	1.0000	.9550	.9070	.9982
UCAV	.8568	.8945	.9550	1.0000	.9911	.9711
UCADJ	.9178	.8270	.9070	.9911	1.0000	.9307
KS87	.7090	.9754	.9982	.9711	.9307	1.0000
UC87	.4466	.9947	.9651	.8440	.7650	.9476

Minimum pairwise N of cases: 3 Significance: * - .01 ** - .001

Correlations:	UC87
SY	.9818
ACSY	.9788
PCSY	.
AGE	-.5195
IPCI	-.6549
PCI89	-.7859
DRATE	.4466
RKSY	.9947
CAV	.9651
UCAV	.8440
UCADJ	.7650
KS87	.9476
UC87	1.0000

APPENDIX C

WEATHER AND POPULATION DATA

PCI, RED BOOK, WEATHER, AND POPULATION DATA - PAVEMENT OF ALL RANKS
(-1 indicates missing data)

	RKSY	IPCI	DRATE	CAV	UCAV	UCADJ	UC87	FREEZE	TMAX	TMIN	SNOW	SNOW87	POPLTN	SSCOST
BRAG	5706	79	2.7	1314146	239	200	95	71	70.1	49.5	7.5	7.9	42325	0.19
CAMP	3477	65	5.1	812803	231	207	100	77	69.3	49.6	11	10	38856	0.12
CARS	1534	64	15.4	1466033	938	788	665	133	62.5	35.3	43.1	44.6	34649	0.22
DEVN	1521	78	2.3	690056	472	340	220	96	55.8	38.3	69.2	71.1	6645	0.15
DRUM	1501	90	2.6	1310918	533	399	2114	90	56.5	38.8	109.9	111.4	42129	0.25
HOOD	5468	81	2.4	1698749	307	280	380	32	77.9	56.5	1.4	1.5	66287	0.18
SAMH	2367	72	2.2	476789	217	208	51	24	79.5	58.4	0.8	0.1	25491	0.2
INDI	1278	75	9.0	258913	185	151	203	95	61.3	44	35.1	26.7	3401	0.1
LEWS	2410	83	3.0	694756	372	303	279	19	59	43.7	12.2	0	57573	0.2
MCCY	1077	63	1.6	303212	277	230	143	96	55.7	37	41.6	37.8	5098	0.09
MCPH	883	81	3.4	391105	705	686	-1	49	70.7	52.2	2	4.2	10121	0.19
ORD	4939	77	2.3	922614	218	163	118	0	64.9	48	0	0	20611	0.06
POLK	4903	70	4.3	1461061	306	243	235	42	75.9	55.8	1.9	.2	30001	0.16
PRES	2414	65	5.1	837941	573	408	246	0	64.9	48	0	0	15960	0.04
RILY	3017	69	19.9	1542729	576	512	-1	105	65.4	43.9	21.5	21.8	61163	0.1
SHER	685	73	2.6	227861	334	285	332	90	58.5	39.4	39.4	42.6	4910	0.25
STEW	2485	89	4.7	1088540	614	574	1116	39	76.1	57.5	0.3	0	24991	0.18
GREE	106	83	2.1	46953	440	167	663	50	36.3	16.2	65.1	39.9	2008	0.15
RICH	739	72	3.3	531764	726	316	1347	107	42.8	28	68.6	79.9	12977	0.08
WAIN	3691	79	1.4	480080	349	110	171	50	36.3	16.2	65.1	39.9	10872	0.25
IRWN	1341	69	5.1	403104	305	215	0	24	80.1	52.3	1.3	0	11914	0.18
BENN	6830	68	4.6	1545270	230	234	92	51	76.1	53.7	0.5	1	46995	-1
CHAF	4357	56	4.8	375733	92	94	47	72	72.1	50.6	6.7	15.8	24824	-1
DIX	1517	84	4.0	629225	415	325	237	86	62.9	46.2	21.6	15	52109	-1
EUST	802	85	2.3	393572	473	384	213	56	68	51.6	7.6	4.7	15413	-1
HILL	1389	86	2.3	303946	333	296	-1	61	66.4	48.6	17.3	25	9743	-1
JACK	2129	74	2.1	353419	167	138	117	70	74.4	52.8	1.8	4.3	20254	-1
KNOX	3368	70	3.8	658394	210	169	113	80	66.1	47.4	17	8.5	37370	-1
PICK	1478	62	3.7	176372	144	127	-1	88	68.8	46.7	14.5	12.6	9480	-1
LEOW	3587	75	4.5	476864	130	97	-1	93	65	44.5	23.2	33	60500	-1
SERA	1801	75	2.7	866683	483	340	1192	24	80.1	52.3	1.3	0	1325	-1
SENE	1242	66	5.3	544691	437	351	493	90	56.5	38.8	109.9	111.4	2042	-1
LHRN	756	73	1.2	49219	65	58	73	80	76.8	50.6	5.9	32.5	998	-1
LSTR	1149	98	3.0	675863	634	576	573	32	77.9	56.5	1.4	1.5	2100	-1

APPENDIX D

ANALYSIS OF VARIANCE TABLES

Variable IPCI
By Variable: Major Command

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	61.1611	30.5805	.3498	.7075
Within Groups	31	2709.8095	87.4132		
Total	33	2770.9706			

Variable DRATE
By Variable: Major Command

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	15.9866	7.9933	.5484	.5834
Within Groups	31	451.8757	14.5766		
Total	33	467.8624			

Variable SNOW
By Variable: Major Command

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	1779.3901	889.6950	.9376	.4024
Within Groups	31	29415.6926	948.8933		
Total	33	31195.0826			

Note: In order to be considered significant, the value of the F probability (F Prob.) must be less than .01

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